Transitioning Between Versions of Traffic Management Systems or Subsystems

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FOREWORD

Traffic management systems (TMS) and traffic management centers (TMC) 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 in 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). Agencies continue to be challenged with improving the performance of their TMSs, expanding the geographical service area, expanding or enhancing services, and providing funding and staffing needed to manage, operate and maintain the systems.

This report outlines the technical and other considerations (e.g., processes, information technology, staffing) needed for executing a transition between versions of a TMS or specific subsystems (e.g., software, computing hardware). The practices and methods captured in this report can assist agencies when they plan, design, procure, develop, implement, test, operate, and evaluate improvements to TMSs. This report may be of interest to representatives from State departments of transportation, local agencies, metropolitan planning organizations, regional authorities, toll authorities, and other groups engaged in transitioning from a current TMS to a new version, replacing a subsystem of a TMS, or adding new subsystems or capabilities to an existing TMS.

Carl Andersen
Acting Director, Office of Safety and
Operations Research and Development

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This report provides an overview of issues and topics to consider when transitioning from a current traffic management system (TMS) to a new version, replacing a current TMS with a new one, replacing a subsystem of a TMS, or adding new subsystems or capabilities to an existing TMS. The report outlines the types of technical and nontechnical considerations for executing a transition, including software, computing hardware, business processes, information technology, and staffing. The practices and methods captured in this report may assist agencies when they plan, design, procure, develop, implement, test, operate, and evaluate improvements to legacy TMSs or in the planning or preparation for the next generation of their TMSs. This report may be of interest to representatives from state departments of transportation, local agencies, metropolitan planning organizations, regional authorities, toll authorities, and other groups who may be engaged in transitioning from a current TMS to a new version, replacing a subsystem of a TMS, or adding new subsystems or capabilities to an existing TMS.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
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)

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

API	application programming interface
ATM	active traffic management
ATSPM	automated traffic signal performance measures
C2C	center-to-center
C2F	center-to-field
Caltrans	California Department of Transportation
CCTV	closed-circuit television
CMS	changeable message sign
CVO	commercial vehicle operations
DaaS	desktop as a service
DMS	dynamic message sign
DOT	department of transportation
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GIS	geographic information system
GUI	graphical user interface
HVAC	heating, ventilation, and air conditioning
IaaS	infrastructure as a service
IGA	interagency agreement
IOO	infrastructure owner-operator
IP	Internet protocol
IT	information technology
ITS	intelligent transportation systems
JSON	JavaScript Object Notation
LiDAR	light detection and ranging
MOU	memorandum of understanding
NoSQL	not only structured query language
NTCIP	National Transportation Communications for Intelligent Transportation System Protocol
PaaS	platform as a service
PPP	public-private partnership
PTZ	pan-tilt-zoom
QR	quick response
RFI	request for information
RSE	roadside equipment
RWIS	road weather information system

SaaS	software as a service
SLA	service level agreement
SQL	structured query language
TIM	traffic incident management
TMC	traffic management center
TMS	traffic management system
TSMO	Transportation Systems Management and Operations
VPN	virtual private network

CHAPTER 1. INTRODUCTION

A traffic management system (TMS) comprises a complex, integrated blend of hardware, software, processes, and people performing a range of functions, services, and actions. TMSs focus on improving the efficiency, safety, and reliability of travel on the surface transportation network. As agencies consider or pursue improvements to their TMSs, they should consider resources that will guide the *transition* to new capabilities, functions, and services.

PURPOSE AND FOCUS ON TRANSITIONING

The purpose of this report is to discuss issues to consider in transitioning from an existing TMS to the next generation of an agency's TMS, subsystems (e.g., data, software, computing, and user functions) or components. The intended audience for this report will gain an appreciation for the subsystems (e.g., software, database, communications), components, and the issues to consider in the processes and functions that support TMSs. This report will benefit practitioners who are responsible for or support a TMS, make decisions that may influence TMS usage, or may be impacted by a TMS's capabilities, management, or operation.

The objectives of this report are as follows:

- Present preparatory issues and actions in support of transitioning between versions of a TMS or TMS subsystems and components.
- Discuss nontechnical issues (staffing, contractual, business processes, resources, etc.) related to transition of TMSs.
- Discuss technical issues in transitioning, including test plans, test procedures, configuration management, and software integration.

This report does not provide a step-by-step process for specific types of transitions or the details regarding the specific subsystems, components, devices, and processes (e.g., testing, acceptance, initiation) that agencies may consider using in support of transitions for TMSs.

Transitioning a TMS includes the following possible scenarios:

- Upgrading a current TMS to a new version (e.g., operating system software).
- Replacing a current TMS with a new or next-generation TMS.
- Replacing a subsystem or component of a current TMS with a new or upgraded subsystem or component.

Transitions are motivated by several factors in the lifecycle of a TMS, including the following:

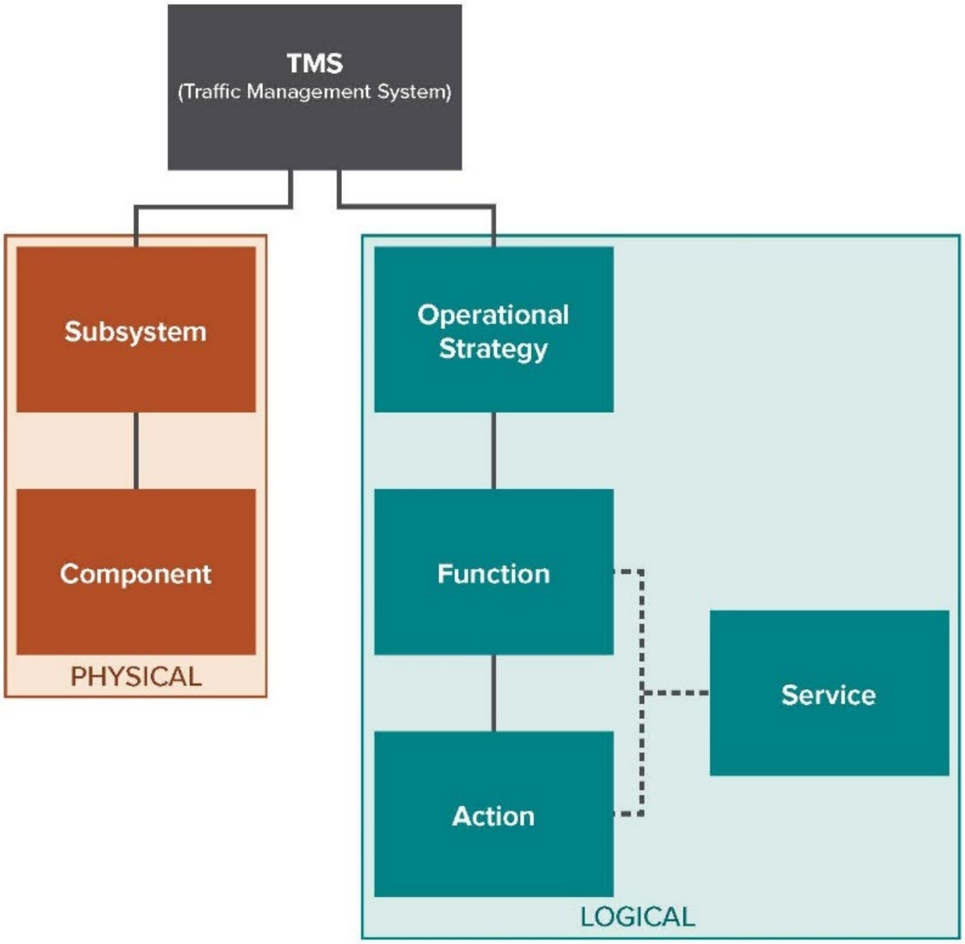
- Providing new operational strategies, functions, actions, or services not possible in existing or legacy systems due to the availability of new technologies or data.
- Increasing capabilities of operational strategies, functions, actions, and services to meet or exceed performance objectives (more capabilities, lower cost, more efficient, more effective).
- Providing the *potential* for new operational strategies, functions, actions, and services through more extensible or flexible platforms.
- Replacing legacy TMSs, subsystems, or components at end of life.

Transitions are a normal and common (although generally infrequent) event in the lifecycle of operational TMSs. The goal of this report is to identify the issues, processes, and services to consider in planning, preparation, and execution of transitions.

BASIC TAXONOMY OF TMS, OPERATIONS, AND SERVICES

The TMS structure has both physical and logical elements. Physical elements include the subsystems and components. The logical elements are the operational strategies, functions, actions, and services. In computer terminology, a logical element converts inputs into appropriate outputs. Similarly, for a TMS, the logical element takes input from physical components and executes operational strategies that have a direct output meant to satisfy a functional or operational need. The implementation of these logical elements is based on the type of roadway being managed, the agency's need, and the geographical extent of the agency's jurisdiction.

Having context for both the physical and logical sides of a TMS and examining how TMS strategies have evolved over time provides a better understanding of agencies' changing needs and how agencies have adapted to meet present-day needs. Figure 1 provides a visual representation of the TMS structure.

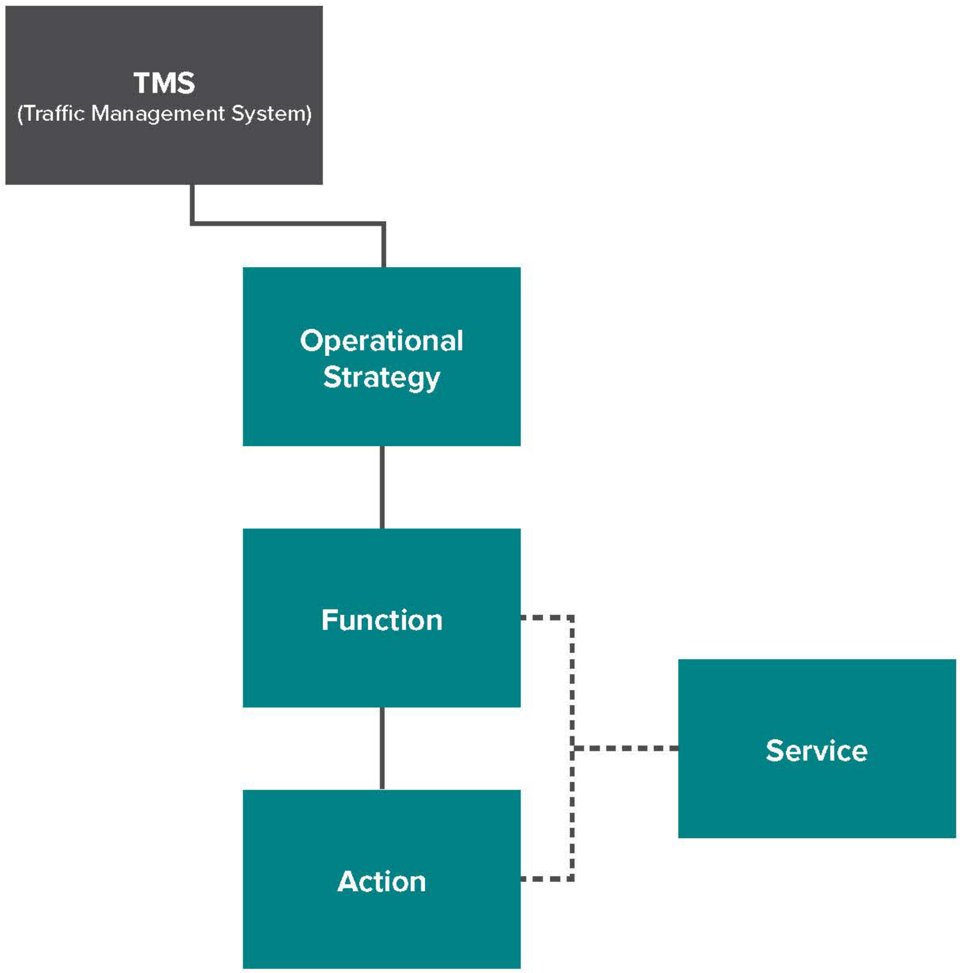


Source: Federal Highway Administration (FHWA).
Solid line = composition; dashed line = realization.

Figure 1. Diagram. General TMS structure.[1]

Logical Elements of a TMS

The logical elements of a TMS are the operational strategies, functions, actions, and services that are implemented in different environments. Figure 2 displays the logical side of the TMS structure.

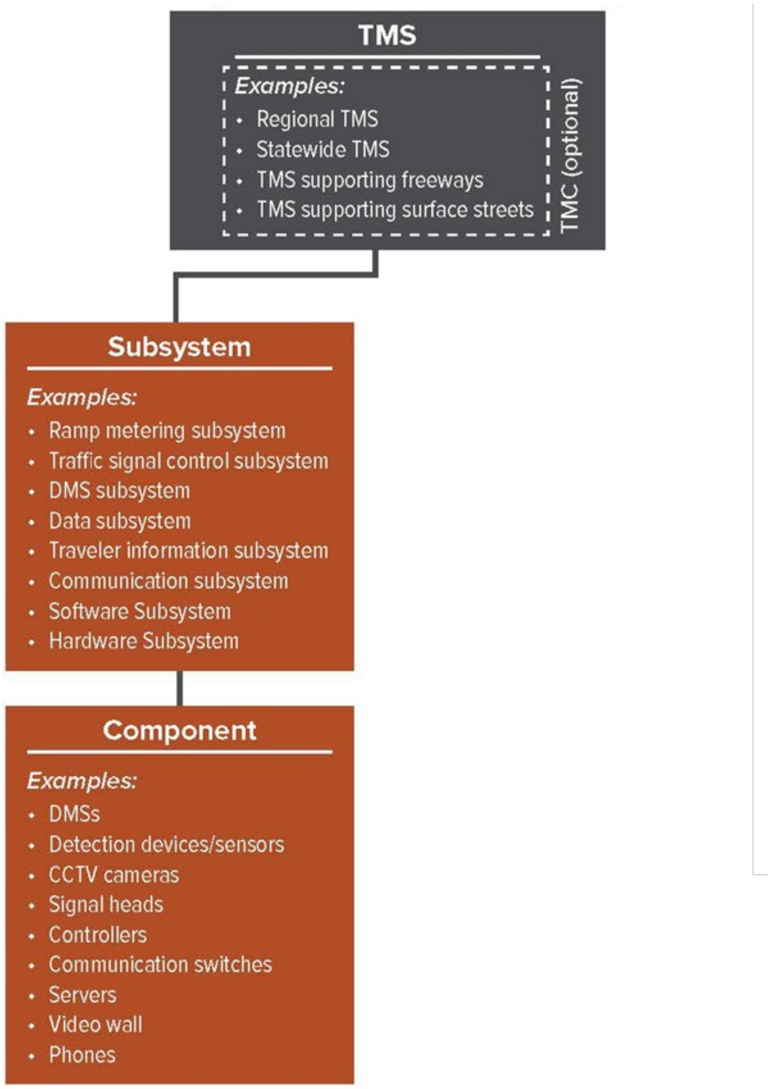


Source: FHWA.
Solid line = composition; dashed line = realization.

Figure 2. Diagram. General TMS structure (logical side).[1]

Physical Elements of a TMS

Many TMSs have a physical TMC that acts as the nerve center of the system, while other TMSs may consist of a computer or tablet on a desk. Regardless of whether a TMS is controlled by a TMC, modern TMSs are complex systems and are typically composed of a suite of subsystems. The subsystems are often composed of an integrated collection of components or ITS components. Figure 3 provides a visual representation of the physical side of the TMS.



Source: FHWA.
DMS = dynamic message sign; CCTV = closed-circuit television.

Figure 3. Diagram. General TMS structure (physical side).[(1)]

Subsystems are often deployed together to enable various operational strategies for meeting agency goals. Components from these subsystems can range from changeable message signs (CMS), detection components, closed-circuit television (CCTV) cameras, signal heads, controllers, communication switches, and other computer technologies—to name just a few. These components may work in isolation from one another or in concert with components serving other subsystems to perform functions to achieve the overall system objectives.

An agency's operational strategies can guide the selection of ITS components and technologies, the subsystem architecture and how the components are linked to the subsystems, and how these strategies and systems work together to meet overall agency goals, objectives, and performance measures.

Types of TMSs

This section addresses the range of architectures, subsystems, components for subsystems, operational strategies, functions, actions, and services supported by TMSs. By considering individual parts of the system, agencies can evaluate how well systems are carrying out needed functions, overall system performance, and (if necessary) determine the need to make changes in how a TMS is actively managed and operated. Additionally, agencies can modify the deployment of operational strategies or services and upgrade or replace individual components or the entire system as needed. In addition to providing some context and examining how these systems operate, this section also includes examples and current practices in successful implementation of TMSs for systems that support freeways, surface streets, and facilities/corridors/regions. These examples show how subsystems and their components should operate, which can help agencies better understand their TMS's current capabilities (and if improvements can be made). Gaining an encompassing understanding ultimately assists in the future development or upgrade of a TMS concept of operations.

Before describing the types of systems that support freeways, surface streets, and facilities/corridors/regions, the report covers different TMS operating models. Some of the most common TMS operating models in the United States include virtual, centralized, distributed and hybrid.

Virtual TMSs

The virtual model uses electronic communication, computing, and software technology to manage and operate TMSs without a physical TMC. The most common approaches to applying this model include staffing and operation by a single entity or management by a single entity with support from other partner agencies. This model may require extensive coordination from participating agencies, depending on the scale (in terms of jurisdiction, geographical area, operational strategies, and scope). An interagency agreement (IGA) may be required. Access to this virtual system may be available to both agency and interagency personnel. Using the virtual model allows costs to be shared among the participating agencies; alternatively, this model may be funded by a single entity.(1)

Centralized TMSs

The centralized operating model includes a central location or facility (typically a TMC) where much of the TMS resides. In most cases, a single entity manages the TMS, with straightforward lines of authority. The operational focus in this model is usually on local issues, but coordination with nearby agencies may still be necessary depending on IGAs. This model can be deployed in a region (e.g., Statewide TMS) or in multiple regions where each region oversees its own area.(1)

Distributed TMSs

The distributed model, which is also called the decentralized model, involves the computers/servers/workstations and staff residing in multiple locations or TMCs. This model is often a joint program where various agencies agree on policies, funding, structure, asset sharing, roles, and staffing. In a distributed TMS, certain TMS functions are distributed or shared among the locations/TMCs. This model allows an agency to maximize its resources, share costs, improve working relationships, and increase efficiency and is typically applied to larger metropolitan areas that cross-jurisdictional boundaries.(1)

Hybrid TMSs

The hybrid model is essentially a combination of the virtual, centralized, and distributed models. This model can be further categorized into hybrid centralized and hybrid distributed, and it can apply to an extended geographical area, including urban and rural regions. In the hybrid centralized submodel, a single entity and all users within that entity share the same network. This network can be accessed via an intranet or virtual private network (VPN). In the hybrid distributed submodel, multiple participating entities can access the TMS from any location with Internet connectivity via the hypertext transfer protocol secure (https) communications protocol. User access and specific system functions are limited to specific users and user groups. Currently, many TMSs in the United States have virtual capabilities; however, these capabilities are typically established for emergency and backup operations rather than as a primary standalone hybrid model.(1)

Operational Strategies

Operational strategies are designed to achieve specific goals or objectives that can be clearly identified and measured. Often, a suite of operational strategies is needed to reach these goals. Agencies can deploy many operational strategies to support TSMO. Some of the more common ones include the following:

- Ramp metering.
- Managed lanes.
- Variable speed limit.
- Dynamic speed advisory/harmonization.
- Traffic incident management (TIM).
- Part-time shoulder use.
- Traveler information.
- Road weather management.

- Queue warning.
- Weigh-in-motion.
- Work zone management.
- Data management.

Functions

Operational strategies are enabled by specific functions and actions. Functions that can be implemented to support these operational strategies include the following:

- Monitoring roadway conditions.
- Collecting weather information.
- Performing roadway weather maintenance.
- Analyzing the collected data.
- Disseminating traveler information.
- Deploying speed limit reductions or advisory speeds.
- Using predictive decision support software to guide operators in system adjustments and overrides.
- Providing traffic detection and surveillance.
- Managing incidents and special events.
- Managing freeway ramps.
- Managing preferential and priced lanes.
- Providing coordination among agencies.
- Monitoring and evaluating system performance.

Actions

These functions comprise basic and singular actions that are performed by a person or a TMS component. The list of actions that could be performed includes the following:

- Monitoring components.
- Collecting data from detectors (including traffic and roadway conditions data).
- Collecting weather data.
- Sending data to storage.
- Sending data to another system or party.

- Sending data to a TMC.
- Displaying traveler information and public advisories on CMSs.
- Displaying speed advisories on lane control signs (LCSs).
- Broadcasting travel advisories or anticipated travel delays using highway advisory radio.
- Displaying CCTV camera images on a video wall or website.
- Invoking a decision, action, or sharing of information based on conditions.
- Confirming incidents.
- Calling incident response units.
- Calling maintenance crews.
- Changing the ramp meter signal head indication.

Services

Operational strategies are also typically supported by services. With the help of communication mediums and mechanisms, these services can be described as a set of functions and actions that allow for system access to be enabled for external parties. Examples of services that can be implemented for operational strategies might include the following:

- A cell phone application that allows travelers to connect to traveler information and data management subsystems and contribute information related to incidents and hazardous roadway conditions. This service can supplement the incident management and traveler information operational strategies by providing additional information to be shared with travelers.

- A mechanism that allows onboard connected vehicle equipment installed on freight vehicles to communicate with the road weather management and data management subsystems to display speed advisories in the freight vehicle when weather conditions limit visibility. This service can also supplement the dynamic speed advisory operational strategy.

- An interface that allows data and information to be exchanged between the road weather information systems (RWIS) and a regional or agency TMS. Most RWISs are separate from TMSs, and this interface helps to facilitate the data exchange. This service supports the road weather management and data management strategy.

- A method that allows data exchange between the road weather TMS and the National Weather Service. This service supports the road weather management and data management strategy.

- A method (e.g., software, algorithms) that monitors, assesses, and offers multiple option responses based on a condition (e.g., after meeting a congestion threshold trigger) from which the best operational strategy, traffic control plan, or action is then selected. This process of assessing, considering, recommending, and selecting is often referred to as decision support.

Transitioning from the previous TMS to a new TMS, TMS subsystem, function, or service is the subject of the remainder of this report.

REPORT ORGANIZATION

The remainder of this report is organized as follows:

- Chapter 2 presents issues and considerations in transitioning from existing to new TMS capabilities, including technical functions (ramp metering, active traffic management (ATM), etc.), operational strategies, subsystems, actions, components, and process-related issues, which include objectives, staffing and agency capacity, and information sharing.
- Chapter 3 presents a logical approach for identifying and prioritizing actions and activities necessary for the transition of an existing TMS or subsystem to a new technology or process.
- Chapter 4 provides an overview of the basic elements expected in a transition plan. This chapter relies on but does not duplicate other U.S. Department of Transportation/FHWA resources, including systems engineering documentation.

CHAPTER 2. ISSUES AND CONSIDERATIONS FOR TRANSITIONING TMS

INTRODUCTION

In this chapter, we will discuss the assessment of capabilities of existing TMS and how agencies may consider these issues in planning for a TMS transition. Evaluating the current capabilities of subsystems (e.g., software, hardware, data), facilities, resources, training, and processes related to a TMS provide the basis upon which to begin developing a transition plan.

This chapter discusses TMS transition issues related to the following:

- Differences in various types of TMSs.
- Agency staffing and capacity for operating and maintaining TMSs.
- Differences in TMS capabilities and functions.
- Operational strategies and services enabled by TMSs.
- Information sharing and data exchange.

TMS OPERATIONAL CHARACTERISTICS

Defining characteristics of a TMS include the following:[1]

1. **Active management.** A TMS provides dynamic and adaptive adjustments to changing current and future conditions.
2. **Operational goals, performance measures, and reporting.** Clear and well-defined operational goals and objectives are core to having a successful TMS and to assessing the performance of the TMS.
3. **Operational strategies.** This characteristic includes the TMS's implemented functions and actions, and services (static, reactive, responsive, and proactive) that support these strategies.
4. **TMS type.** The type includes centralized, distributed, virtual, hybrid, and temporary TMS.
5. **Geographic extent.** This characteristic describes the area in which a TMS serves and could include multistate, State, regional, multiagency corridor, city/county, partial agency coverage, or individual locations.

Generally, a transition becomes more challenging as any of these characteristics increase in complexity:

1. **Active management**—Transitioning from TMSs that provide "passive" traffic management functions (e.g., fixed-time ramp metering, time-of-day arterial traffic control, lack of wrong-way driving detection, etc.) to active functions (e.g., adaptive traffic control, real-time detection of wrong-way driving, weather-responsive functions, etc.) can present many challenges.

[1]Additional detail is available in FHWA *Review of Traffic Management Systems—Current Practice*.[(1)]

2. **Operational goals, performance measures, and reporting**—Transitioning from TMSs that currently do not support performance measurement and reporting to subsystems that provide such functions can involve complex integration projects.
3. **Operational strategies**—Adding new strategies such as integrated corridor management, adaptive ramp metering, or adaptive traffic control can present additional considerations for staffing, training, information sharing, hardware, and software. In addition, transitioning an existing on-premise TMS system or subsystem to a cloud-hosted service presents additional considerations for security, privacy protection, maintenance, and ownership. Similarly, consolidating regional TMSs into a centralized system (or vice versa) presents organizational and technical challenges to be addressed during the transition.
4. **Geographic extent**—Expanding coverage to new regions or areas presents additional coordination issues during the transition process.

Integration of functions typically results in improved efficiency and effectiveness. Replacement of aging (and unsupported or deprecated) services also is a common transition activity.

Activities that an agency will usually undertake when planning for transitioning a TMS may include the following:

- An assessment of conditions, features, capabilities, strengths, and weaknesses of the existing TMS.
- Identification of goals and objectives for the transition.
- Identification of key performance indicators, metrics, and methods of performance measurement for transition effectiveness.
- Development of plans for transition, replacement, or enhancement of legacy/existing TMS.

DRIVERS OF CHANGE SUPPORTING PLANNING FOR A TRANSITION

The drivers of change in transitioning to the next generation of TMSs may include the following:

- Providing *new* functions, operational strategies, subsystems, actions, and components not possible in existing or legacy systems due to the availability of new technologies.
- *Replacing* existing or legacy functions, operational strategies, subsystems, actions, and components to meet performance.
- Providing the *potential* for new functions, operational strategies, subsystems, actions, and components through new technologies or more extensible or flexible platforms.
- Replacing legacy systems at end of life.

All these drivers of change should be considered as agencies transition an existing TMS. As the following information shows, different types of transitions entail different levels of complexity:

- **Transitioning to a new version of an existing system**. This transition is generally the least complex. Fewer "unknown unknowns" are likely to occur with this approach.

- **Transitioning to a new subsystem or component.** This transition might be considered medium-complex. Many elements of the existing TMS will be retained, so a higher likelihood exists of collaboration between the existing supplier and the incoming supplier that is providing only a specific subsystem. Open lines of communication and a comprehensive transition-planning effort will maximize the chances for success.

- **Adding new functions, components, or services not available in the existing TMS**. This transition also might be considered of medium complexity. All elements of the existing TMS are retained, but some data sharing is needed between the existing system and the new services and components.

- **Transitioning an existing TMS to a new TMS**. This transition might be considered the most complex. The incoming supplier may not have the institutional knowledge of the existing supplier, and the existing supplier may be reluctant to collaborate with its replacement. In some cases, wholesale replacements can be relatively straightforward. This scenario is most evident when the subsystems and the field devices of interest fully support national standard protocols such as the National Transportation Communications for Intelligent Transportation System Protocol (NTCIP). Typically, legacy and ad hoc protocols present a number of challenges. Significant effort during the transition planning phase will be very important to ensure a smooth transition.

This report focuses on the *tactical* planning aspects of transitioning, such as technology choices, software considerations, deployment (e.g., cloud, on-premise), procurement methods, information technology (IT) considerations, and staffing.

Chapter 4 discusses the content of a transition plan. Knowing what will be included in the plan can provide valuable context for the following sections. A typical transition plan will include the following:

- **Articulation of the "why"**: Goals and objectives for the transition.

- **Articulation of the "what"**: Functions, services, actions, and subsystems to be transitioned. Agencies should specifically identify, in as much detail as possible, what needs to be done to achieve the transition.

- **Articulation of the "how"**: Details of activities to accomplish the list of items in the scope of work (the "what").

- **Articulation of the "who"**: Groups and persons (preferably individual names) responsible for leading tasks and accomplishing activities.
- **Articulation of the "when"**: The schedule and dependency of activities on downstream work.

SUPPORT CONSIDERATIONS FOR TMS TRANSITIONS

TMSs enable staff to perform many of the transportation systems management and operations (TSMO) activities that support the missions of infrastructure owner-operators (IOO). During a transition, an agency should consider that the existing system and the supporting procedures and processes are likely to be in use as the transition occurs. Evaluating who needs to take ownership of certain activities and what the scope of those activities will be is an important element of the transition planning process.

Key issues to consider in support of planning, preparing for, or conducting TMS transitions may include the following:

Policies

Agency policies to be considered when planning to transition a TMS include allowable and disallowed actions, responsibility designation, IGAs, and legal/liability issues. Many agencies do not have or have not established such policies in written procedures but address them through administrative software permissions, limitation of partner agency access to certain functions, or via other software features, such as denylists of inappropriate words for CMS or other traveler information outlets. Other agencies establish such policies in IGAs or memorandums of understanding (MOU), particularly when multiple partners are involved in a TMS project.

Individual agencies typically have handbooks or procedures that describe what to do (business process) but not necessarily why to do something or not do something (policy). During a transition, an agency may need to review these policies and procedures to address changes in the way a new TMS or TMS subsystem may be different. Any new functionality must be supported by policy.

As an example, many TMS policies involving multiple partner agencies may restrict the pan-tilt-zoom (PTZ) capabilities of partners' access to CCTV cameras. The owning agency is typically allowed to move the camera and the partners cannot. Other policy agreements may allow agency PTZ capability but have a "time out" parameter that automatically moves the camera back to a preset view. During a transition to a new TMS, such features may have been previously unavailable or implemented via different means. Agencies should be careful to consider that transitioning to a new TMS may require different relationships between partners.

Similarly, agencies may allow other partners to post messages on their CMS signs with no restrictions or only allow partners to post messages of certain priorities. Newer TMSs may allow agencies to have first right of refusal to deny a certain message being posted if their local priorities are more important. For example, during a football game, a local agency responsible for managing traffic ingress and egress to the stadium may wish the CMS boards to retain messages related to parking availability and deny a partner agency to post a general public service announcement (PSA) on the signs surrounding the stadium. As the next generation of agencies' TMSs continue to include more interagency partnerships and information sharing through technology, agencies need to address policy issues in the feasibility analysis and planning stages to ensure that software and TMS features address or support acceptable or unacceptable actions.

Another TMS policy that may need to be addressed is the provision for partner agencies to operate TMS functions on behalf of another agency, typically during times when the local agency staff are not available. In many jurisdictions, TMCs responsible for freeways may be staffed 24 h per d/7 d per wk, while TMCs responsible for traffic on surface streets may be staffed during typical business hours, during special events, or only occasionally. Transitioning to a next-generation TMS may allow interoperability among partners' TMSs versus previous implementations of control-sharing, such as a dedicated workstation (or Web-based graphical user interface (GUI)) for the control and monitoring of partner assets.

Agencies and their partners may need to review and update IGAs based on new capabilities of the TMS. For example, in San Mateo County, CA, the California Department of Transportation (Caltrans) District 4 can send commands to local agency traffic signals through center-to-center (C2C) software connections during incident diversion. No local agency actions are required. Before this next-generation service was implemented, multiple workstations and services would have been required to enable such interjurisdictional control.

Another example of TMS policy implications for transitioning to the next generation of TMS involve agency policies regarding allowed and disallowed traffic control strategies. For example, 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 (for example) does not allow for protected-permitted left turn on green arrow signal indications on State arterial routes. This policy again reduces traffic efficiency but reduces crashes caused by drivers who misjudge their ability to cross in a gap in oncoming traffic or by drivers who misinterpret the circular green signal indication as protected versus only permitted. Such policies have implications for a transition to specific new TMS services such as adaptive traffic control and alternative incident response timing plans.

Another policy example is related to cloud computing and cybersecurity. Many transportation system management groups within larger agency organizations (e.g., State department of transportation (DOT) as part of the State Government) have traditionally managed their software, hardware, and IT systems separately from the State's broader IT organization. As such, the State DOT IT department may have different policies regarding cloud computing and services than other State agency IT departments that deal more heavily with services related to payments and storage of citizens' personally identifiable information (PII) (motor vehicle registration, driver's licensing, water service billing, property tax collection, etc.). New partnerships with agency IT may be necessary to address appropriate policies for cloud computing when transitioning a TMS to a cloud tenancy that traditionally did not have the same security breach risks as other departments, such as health and human services, department of motor vehicles, or taxation. The DOT IT department may have a long list of potential security issues that may need to be addressed at the policy level and that were largely unnecessary with on-premise deployments of TMS systems and services in the past.

A final example of agency policy regarding transitioning TMSs is sharing of data and records with third parties, such as lawyers representing crash victims. In the past, many TMS agencies may have decided not to record and store CCTV video as a policy so that such records requests do not overwhelm staff that have other significant duties. Arterial management agencies may have only had access to basic traffic signal operational parameters (cycle, splits, offset, etc.) but not the high-resolution, second-by-second time-stamped signal-interval changes in the legacy TMS. As next-generation TMS subsystems may inherently enable new data recording and resolution capabilities, new policies may be necessary to address public records requisitions.

Procedures and Business Processes

Business processes are a set of activities and tasks that allow organizations to accomplish their goals. Procedures are specific ways in which an organization carries out an activity or task. TMS procedures and business processes include a range of agency standards most often applicable to certain functions and subsystems, such as posting messages to CMS, incident response and event management, operation of lane control signs or gantries, and recordkeeping. More agencies are codifying such business practices in written procedures, handbooks, and staff position responsibility descriptions as part of TSMO program plans.

Similar to policies, certain IGAs or MOUs may describe business process elements that were necessary with legacy TMS but can now be handled differently when transitioning to a new TMS system or subsystem. Agencies should consider what changes in procedures and business processes may be needed to support the new or updated TMS. These changes may be identified in the TMS plan but will be implemented during the transition process.

Because TIM is a longstanding and critical function of freeway TMSs, most agencies have established very detailed procedures for how information on incidents may be recorded, managed, and shared. For example, TMSs may use multiple approaches to automate functions or actions to reduce the burden on operators to correctly allocate the lane control signs on multiple gantries upstream of a downstream of traffic incidents. IOOs may have similar evolving practices regarding the use of shoulders as travel lanes. While efficiency may be improved during incidents, the use of shoulders may increase the response times of first responders. Transition planning for new TMS operational strategies (e.g., lane control, use of shoulders) and functions should consider the ancillary impacts on previous business processes.

Another common business process of TMSs that may be affected by a transition to next-generation technologies is field equipment management, which has been historically less regimented (i.e., less formalized and not well documented) for traffic and ITS devices than for assets such as bridges and pavements. While most agencies have comprehensive maintenance management solutions available, these solutions may not be used for ITS and traffic control device tracking.

For multiple groups within an agency to have responsibility for one type of device (fiber plant, switches) while another group is responsible for another device type (traffic controllers, ramp meters) is not uncommon, with each group using different tracking systems (spreadsheets, databases, geographic information system (GIS) tools, etc.). Next-generation TMSs may include integrated maintenance tracking systems that both groups may find useful, but individual group business processes may require different workflows for each or require conversion of one group's workflow to match that of the other group. While harmonizing agency group workflows during a transition to a next-generation TMS may seem simple enough, such processes are commonly quite detailed and developed over years of experience, with many good reasons why something is done one way versus another.

Addressing business process issues in transitioning to the next generation of TMS may prove challenging, particularly where multiple agencies (State DOT and local agencies, for example) are deploying the system together with similar but different approaches to device management and business processes.

Resources, Staffing, and Contracting

TMS resources and staffing vary broadly across different types of agencies. Many small agencies may have no dedicated staff for a TMS, while large State DOTs may have multiple operators and engineers in a TMC 24 h per day, 7 d per week. Many agencies also may outsource such services to the private sector, ranging from semipermanent multiyear extension-of-staff contracts to traffic-engineering consultants that respond to citizen complaints on an agency's behalf. Necessary staffing and contracts to support the new or updated TMS should be in place when the transition process is complete, otherwise, realization of the full capabilities and benefits of the new or updated TMS may delayed.

The Georgia DOT (GDOT), for example, has outsourced all arterial traffic management responsibilities to consultant teams throughout the Atlanta metro region. This regional traffic operations program has been successful in transitioning traffic management responsibilities from overtaxed local agency staff to consulting engineering firms that are financially incentivized to maintain performance objectives such as device uptime, maintenance issue resolution time, and congestion levels on arterial streets.(2) This traffic operations program requires close coordination among the consultant teams and GDOT and strong specification of business processes during the transition phase so contractors can perform their activities in as similar a manner as possible.(3)

Upgrading to the next generation of a TMS may allow agencies to reassess the ratio of staff needed to perform functions, reevaluate the need for certain manual processes, reduce or expand operational hours, provide capabilities for remote access to system functions, and more. In the reverse, next-generation TMS functions also may require additional staff or staff with different skills, such as data science, IT (e.g., computer processing), or communication networks. Providing new TMS functionality may impact the requirements for new or existing positions, may involve new capabilities or retraining, or require reassignment of staff (IT hardware and software responsibilities, in particular) to support operations during the transition process.

Physical Facilities and Centers

During the transition period for a new TMS system or subsystems, centers may need to obtain additional computing facilities (server racks), more capable servers, virtualized server clusters, networked storage arrays, upgraded router capacities, fiber optic cabling in lieu of serial interconnect cables, additional monitors and workstations, modern video wall facilities, touchscreen and smartboard monitors, audio inputs (such as speech command microphones), collaborative table computers, and other advanced technologies. More computing and network switch inventory may require upgrades to physical building heating, ventilation, and air conditioning (HVAC), fire suppression, generator capacity, breaker circuits, and/or physical server room space. Updated policies, procedures, and processes should be established by the end of the transition. Agencies should also review the supporting requirements of a new or updated TMS when planning the transition to ensure these items are in place by the time the transition is complete.

ISSUES TO CONSIDER FOR TMS TRANSITIONS

In transitioning from current TMS to an improved, next-generation TMS, or new subsystems, agencies may consider a variety of topics. These topics are categorized by agency capabilities. The agency capabilities to consider in a TMS transition context may include the following:

- Systems and technologies.
- Staffing and organization.
- Business processes.
- Collaboration with other departments and agencies.
- TMS performance measurement (capabilities and expectations).

This section discusses the issues that an agency may consider when planning for and implementing a TMS transition in the form of a series of checklist questions. The earlier the needs and resources to support transitioning are identified and considered in the feasibility or improvement planning process, the greater the chance these needs are addressed for a smooth and efficient transition. No "right" answers exist, and every question is not applicable to every possible transition activity or situation. These checklists are provided as a starting point for an agency's transition plan and to assist in ensuring that the plan covers all the bases of potential challenges and resources needed to support a transition. Agencies can use questions that highlight an area of concern (for example, lack of training on new technologies, adopting wholly new processes, using cloud-based IT with no previous experience) to frame the need for additional budget, longer schedule, additional staff involvement (particularly IT professionals), resources, and needs for detailed tactical transition plans.

Systems and Technologies

TMSs are based on software, databases, computing hardware, telecommunications networks, and IT. Among the topical categories listed in the Issues to Consider for TMS Transitions section, systems and technology issues may pose the most challenging issues for transitioning. TMSs monitor, compile information, and initiate actions in two basic ways:

1. **Database applications** where staff enter details of events, incidents, asset characteristics, or log actions or to-do lists for maintenance staff. Databases may include spreadsheet software or other storage formats, including GIS, web pages and websites. These database applications may feed data into real-time TMS applications, display data on external websites, or exchange information with 511 or other partner agency systems.
2. **Real-time or near-real-time applications** where field-device component status is collected on a regular basis, operational strategies are configured, and actions are taken

by system operators. Maps, lists, and other displays indicate real-time status and control actions of field elements.

Database applications may have the following characteristics relevant to transitioning:

- Software tools may be unsupported, are past end of life, or require specific versions of software libraries or operating systems.
- Interfaces may be difficult to expand or enhance or lack the ease of use of modern GUIs.
- Storage formats may be unsupported or require translation to modern formats.
- Applications and data may not be easily shared across networks.
- Applications may have security vulnerabilities or use of outdated components that do not comply with agency IT policies.
- Only certain staff may be responsible for and knowledgeable about operation and maintenance of the application.

In addition to these characteristics, real-time and near-real-time applications may have the following characteristics relevant to transitioning:

- Field devices may use custom protocols.[2]
- Support documentation for protocols and/or configuration of field devices may be unavailable.
- Not all applications may support protocols of newer devices, other manufacturers, or data exchange formats.
- Field devices may use specialized hardware that cannot be repaired due to lack of spare parts or replacement boards.
- Communication links (serial, dial-up) may not support high-speed or high-bandwidth data exchange.
- Field device command and control may be siloed in multiple applications, with multiple databases and interface formats.
- Operational strategies may be "hard coded" or difficult to configure or change.

[2]A protocol is the technical description of how one system obtains information and sends commands to or receives commands from another subsystem or component. NTCIP 1202[(4)], for example, describes how a centralized TMS obtains second-by-second status data and communicates with a traffic signal controller.

Many next-generation TMS functions may include some level of consideration of cloud services. Transitioning to the cloud includes many potential issues, including cloud data storage, computing, and software services. DOTs vary widely in IT policies and procedures pertaining to the consideration of cloud applications and technology, as discussed in the policy section of chapter 2. Partnering with the IT department early in the planning for possible improvements to TMSs and development of transition plans is important to successfully developing, deploying, and initiating TMS improvements.

The following issues in software, databases, and IT are important for agencies to consider during a transition:

Table 1. Software, databases, and IT checklist.

Questions	Complete?
What operating systems do we use currently? Linux, MacOS, Windows? What operating systems are used by the proposed TMS, subsystem, or components?	☐
Can we or should we consider other operating systems beyond those we currently use?	☐
Do we have experience with other operating systems used by a next-generation TMS technology or system? If not, can we rely on the supplier to maintain the operating system?	☐
What databases do we use currently? Relational database, object oriented database, structured query language (SQL), NoSQL, open source, or something else? What databases does the new TMS use?	☐
Can we or should we consider other databases in the new TMS beyond those currently use?	☐
Do we have experience with other databases used by the next-generation TMS technology or system? If we do not, can we rely on the supplier to provide support?	☐
How do we deploy databases? Can existing clusters or virtual machines be used for next-generation TMS applications?	☐
What other on-premise computing resources will be required? Do we have adequate space for new hardware in existing computing and data centers?	☐
Do we have experience with the next-generation TMS applications that require merging data from multiple sources and formats?	☐
What database and operating system technologies do our current TMSs rely on?	☐
How will we integrate our legacy TMS with new next-generation TMS software?	☐
Can we or should we replace or integrate certain elements of legacy TMS systems with next-generation TMS software?	☐
Will we need to (and can we) operate both systems in parallel during the transition? Will we establish a test environment for the next-generation TMS or use a subset of live devices for next-generation deployment?	☐

Questions	Complete?
Will our existing field devices work with the new TMS? Will we consider device replacement? Will or can we consider device upgrades? Can a protocol translator be developed? Should such a translator be developed?	☐
What application programming interfaces (API) do our current legacy TMSs have? If APIs currently do not exist, can they be developed?	☐
What API standards do we support? Can the next-generation TMS software or systems use these API standards, or will new integration be required?	☐
How much of the system will be deployed on-premises versus in the cloud?	☐
Can we use public cloud hosting, or do we need a private cloud or hybrid cloud environment?	☐
Are certain cloud services tied to specific cloud providers, or can the services be deployed in any tenancy?	☐
What sensitivities to data protection and PII does cloud usage for next-generation TMS applications present? Do we know what requirements or organizational policies are already in place for handling cloud applications and data storage?(5)	☐
Do cybersecurity issues need to be addressed when using next-generation TMS applications? What vulnerabilities or sensitivities may arise by use of next-generation TMS software?	☐
What policies or procedures are necessary for use of open-source, next-generation TMS software?	☐
What policies or procedures are necessary for use of vendor-proprietary or trade-secret next-generation TMS software?	☐
What procurement models and methods of procurements can we use and have experience with? Does our organization preclude use of any procurement method?	☐
Have we appropriately considered service level agreements (SLA) for the next-generation TMS? Are the SLAs appropriate for the mission-criticality of the application(s)?	☐
Can the next-generation TMS software and supporting databases and systems be procured as software as a service (SaaS)? Platform as a service (PaaS)? Infrastructure as a service (IaaS)? Desktop as a service (DaaS)? Traditional licensing?	☐
Do we understand how software maintenance, updates, upgrades, and modifications will be handled?	☐
Have we appropriately considered the level of support necessary from the next-generation TMS supplier? Do we understand the cost implications of comprehensive support, such as 24/7/365?	☐
Do our current vendors of TMS and related systems have experience with next-generation TMS applications?	☐

Staffing and Organization

Use of new operational strategies, functions, or services may involve technical capabilities or requirements that exceed the existing level of in-house expertise in most agencies. Similarly, agencies may need to make organizational decisions regarding which department(s) or agency staff to involve in the transition plan and be responsible for the success of the transition.

Table 2. Staffing and organization checklist.

Questions	Complete?
Do we have a champion for the transition to next-generation TMS systems?	☐
Is this champion in our organization?	☐
Does our organization embrace technology and innovation? Does leadership commit to advance technology with appropriate levels of funding and resource allocation?	☐
Can we take tangible steps to promote a culture that embraces new technology?	☐
What groups or divisions will have primary involvement in transitioning, deploying, operating, or maintaining next-generation TMS applications and related infrastructure?	☐
Which division of the organization will be responsible for success of a transition? IT? TSMO? GIS? Other?	☐
Can we partner with other divisions or groups within our organization that also are interested in transitioning to next-generation TMS technologies?	☐
Are other departments or partner agencies already using next-generation TMS and/or underlying technologies (cloud databases, APIs, data exchange, etc.) in some way that can help us? How can we engage those partners?	☐
What basic and advanced skills are needed for the transition, and does our staff have these skills?	☐
What specific technical areas do we have that can support transition of next-generation TMS technologies? • System engineering? • Next-generation TMS design? • Next-generation TMS deployment/integration? • Transition planning? • Data management? • Operations? • Maintenance? • Analytics?	☐
Do we have flexibility to acquire agency staff with these skill sets (i.e., redefine roles, expand technical staff groups) for the transition? What retention issues might we experience with highly skilled staff?	☐

Questions	Complete?
Do we have a mechanism to obtain new skills if they cannot be addressed by current staff or roles (i.e., contract/outsource, training)?	☐
Do any operational or policy limitations affect our agency when transitioning to next-generation TMS applications? How do we remove such barriers if they exist?	☐
Do we have significant understanding of or are learning about peer agency programs and experiences with transitions, national trends, and next-generation TMS technologies?	☐
What training will staff need to transition, develop, deploy, operate, and maintain next-generation TMS systems?	☐
Will agency leadership commit to continuing with next-generation TMS systems? If a pilot "fails," does this affect future decisions for transitions?	☐

Business Processes

Transition to new operational strategies, functions, or services may involve new business processes such as transition planning, scheduling, budgeting, and project development. The changes may involve new processes for things such as data collection, data exchange, and information display. This transition is especially important if the operational strategy is not a TSMO strategy an agency currently uses. In such cases, the agency likely has not already initiated efforts to advance these new business processes through TSMO or TMS program or planning. An agency may need to transition to an institutionalized approach for new capabilities or services (e.g., security, management of sensitive information) versus developing policies, procedures, or practices.

Table 3. Business processes checklist.

Question	Completed?
Have we developed the business case for transitioning to a next-generation TMS application or program?	☐
Have we engaged with partner agencies that have piloted or used next-generation TMS in a similar manner? Do we understand those agencies' lessons learned during and/or after the transition?	☐
Have we documented the relationships between existing TSMO processes and transitioning to new next-generation TMS capabilities?	☐
Have we documented a communications strategy for public and internal benefits of business process standardization during a transition to a next-generation TMS?	☐
Have we developed an interdepartmental consensus framework for policy and planning for the transition to a next-generation TMS?	☐

Question	Completed?
Have we documented which next-generation TMS applications and functions will provide benefits to our specific regional issues? Can we expect the transition to produce immediate benefits? Medium-term benefits? Is the generation of benefits dependent on actions by third parties?	☐
Have we identified the benefits for a transition? • Reduction in process steps? • Reduction of time for a human to complete an activity? • Improvement in timeliness of actions? • Reduction in complexity of processes? • Improvement in quality of solution? • Improvements in traditional metrics (travel time, congestion, delay, customer satisfaction, etc.) ?	☐
Have we developed a transition plan to address regional processes and relationships among partner agencies for more holistic deployment of next-generation TMS applications?	☐
Have we developed a plan to secure the costs and resources required for transition to next-generation TMS technologies?	☐
Have we gained agency buy-in for how these costs and resources will be borne, both for the transition phase and the operations and maintenance phase?	☐
Have we developed a plan for security and privacy management of next-generation TMS applications and data? Can the management elements be phased in over time?	☐
Have we developed a plan for implementation of the concept of operations during the transition? Do we understand what a next-generation TMS application will do (differently), and what it will not do? Will the operation of the next-generation TMS be different during the transition phase versus the operations phase?	☐
Have we developed a plan for transition of the business processes related to a pilot deployment(s)?	☐
Have we identified roles and responsibilities within and among agency partners for implementation of the transition plan and eventually for the business process operation phase?	☐
Have we considered the implications of potentially having a next-generation TMS make decisions on behalf of the agency without staff interaction? Does the transition plan address this?	☐
Will we require the next-generation TMS to only make recommendations and not implement decisions? Can a hybrid approach be used during the transition phase?	☐

Collaboration With Other Departments and Agencies

Transition to new operational strategies, functions, or services may involve software and computing hardware tools and resources that may not have been used previously to support a TMS. These new tools and resources many involve other organizational groups, departments, and cooperating agencies in the planning for possible TMS improvements or the development of resources and plans to support transitions to new subsystems or a TMS. Collaboration with these different groups to share costs, expertise, and responsibilities may be beneficial. During the transition phase, the answer to these questions may inform the issues and resources to include in an agency's transition plan.

Table 4. Departmental and agency collaboration checklist.

Questions	Complete?
Will established regional or interdepartmental goals be achieved through transition to next-generation TMS applications? Are multiple departments in my agency interested in advancing next-generation TMS capabilities?	☐
Have potential roles and responsibilities been identified for implementing or piloting next-generation TMS capabilities?	☐
Does a forum exist for partner agencies or departments to collaborate/discuss/ obtain consensus on potential next-generation TMS applications?	☐
Do opportunities exist to leverage existing processes among agencies (business processes, planning, procurement, system engineering, and operations) to initiate next-generation TMS capabilities?	☐
Do other departments or partner agencies have experience with next-generation TMS applications or component technologies (databases, data sharing platforms, cloud services, etc.) already? How can these departments and partners be engaged?	☐
Do some partner agencies have fewer barriers to implementing certain processes? How might this difference in barriers influence our planning for transition to next-generation TMS applications?	☐
Do departmental processes need to be considered when piloting next-generation TMS capabilities (i.e., transportation improvement plan, programming and budgeting cycles, and flexibility to fund near-term improvements)? Can a "pilot" be conducted without a commitment to transition?	☐
Do any partner agencies or departments have staff with skill sets that would align with next-generation TMS capabilities? GIS? IT? Surveying? Asset management? Maintenance? Can staff be leveraged to assist with the transition plan?	☐
How aligned are partner agency missions with the TSMO mission with respect to transition to next-generation TMS applications? Do partner agencies or departments have consistent interest and leadership support in this transition?	☐

Questions	Complete?
How involved are our existing private-sector vendors, suppliers, and consultants in next-generation TMS initiatives? Do they have the skills to effectively develop a transition plan? Do barriers exist for engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers? What if any conflicts of interest should be considered?	☐

TMS Performance Capabilities and Expectations for a Transition

One common motivation for a developing a transition plan and identifying the needed resources is increased expectations regarding performance capabilities of TMS. Goals may include improvements to traditional traffic performance measures such as reductions in crashes or congestion and more internal measures for the TMS agency such as improvements to field device uptime, reduced time for TMS users to complete tasks, improved quality level of detail of situational awareness, and expanded geographic coverage of applications or functions.

Performance monitoring of TMS functions for a transition may include a wide variety of metrics depending on the function, application, and business process. Agencies need to establish baselines before identifying improvements through next-generation software, hardware, and business process changes. Some example performance monitoring metrics that could be considered for TMS transitioning include the following:

- The number of field devices online for existing functions (signals, ramp meters, RWIS, etc.).
- The reliability of communications to existing field devices (uptime), including any correlations of communications reliability in regions affected by common fiber or wireless trunk backhaul.
- The extent to which the agency has regional coverage of relevant TMS functions that may be addressed during a transition (freeway service patrol, CCTV, CMS, RWIS, adaptive/active traffic control, etc.).
- The extent of the regional communications network, including bandwidth, communication type (wireless, fiber, serial, Internet protocol (IP) over copper, etc.), existing loading, and available margin or lack of margin.
- Trends in regional performance such as hours spent in congested conditions, crashes and secondary crashes resulting from incident conditions, and average and variability of time to clear incidents (response, clearance, recovery).
- Time taken by TMS operators and users to achieve certain functions or implement changes to functions, including lack of capabilities to affect change in field operations in a timely manner, or at all.

- Statistics related to work zone deployment, activity, information sharing, and traffic control response effectiveness or lack of effectiveness.

Where such information is not available from existing/legacy TMSs, a transition to a next-generation TMS may be able to provide quantitative assessment of regional asset health, status, and effectiveness. The following representative questions may be helpful in identifying performance monitoring issues to be addressed during a transition.

Table 5: Performance monitoring checklist.

Questions	Complete?
Have we identified baselines for performance monitoring of existing TMS? How will we monitor performance of the new TMS?	☐
If baselines have been established, which are tracked and which need to be added? If new tracking is necessary, have we identified the steps necessary to begin tracking such metrics? Are any candidate next-generation TMS able to generate the metrics after a transition?	☐
Does a forum exist for partner agencies or departments to collaborate/discuss/obtain consensus on potential next-generation TMS applications and issues related to transitioning?	☐
Do opportunities exist to leverage existing processes among agencies (business processes, planning, procurement, system engineering, and operations) when initiating a transition to next-generation TMS capabilities?	☐
Do other departments or partner agencies have experience with next-generation TMS applications already? How can they be engaged?	☐
Do some partner agencies have fewer barriers to transition processes? How might this influence planning for a transition to next-generation TMS applications?	☐
Do we need to factor in any departmental processes when piloting next-generation TMS capabilities (i.e., transportation improvement plan, programming and budgeting cycles, and flexibility to fund near-term improvements)?	☐
Do any partner agencies or departments have staff with skill sets that would align with transition to next-generation TMS capabilities? GIS? IT? Surveying? Asset management? Maintenance?	☐
How aligned are partner agency missions with the TSMO mission with respect to transitioning to next-generation TMS applications? Do partner agencies or departments have consistent interest and leadership support?	☐
How already involved are our existing private-sector vendors, suppliers, and consultants in next-generation TMS initiatives? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐

SUMMARY

The questions in each of the previous tables may assist agencies in evaluating the feasibility and effort needed to transition from an existing or legacy TMS to the next generation or an entirely new TMS. In considering a transition, agencies should not only assess issues related to software and functionality but also processes, staffing, procurement, and support. In addition to considering individual functions separately, agencies increasingly consider how subsystems and functions interact with each other, how new capabilities may be supported by different subsystems (e.g., software, computing, data, telecommunications), and what issues and support resources could support the transition to the next-generation or a new TMS, including the following:

- Interaction of signal systems with freeway management functions (e.g., ramp queue management, lane control, use of shoulders, ramp metering).
- Generation of incident response plans with coordinated and automated CCTV surveillance, CMS messaging, lane control, and traffic signal control.
- Preparation for coordination of infrastructure-to-vehicle functions with incident response.
- Integration of device maintenance databases with real-time operations software.
- Cross-jurisdictional traffic management and control.
- Data sharing with the public, third parties, and other IOO stakeholders.

The next chapter identifies some key elements of the feasibility assessment of transitioning from a current-generation TMS to the next generation.

CHAPTER 3. FEASIBILITY ASSESSMENT OF TRANSITIONING A TMS

INTRODUCTION

This chapter outlines issues to consider when assessing the feasibility of transitioning a TMS to the next generation or replacing or adding a subsystem or components. Although the items to consider will mostly be the same regardless of the type of transition, the more complex the TMS, the more complicated the transition will be. For example, replacing an entire existing TMS will result in a more complicated transition than adding a subsystem or component to an existing TMS. The complexity of the transition and needed resources should be reflected in a transition plan.

The specific topics covered in this chapter include the following:

- What to include in a transition plan
- What process to consider in support of conducting a transition
- What activities and resources may be needed to support a specific transition.
- How the planning for and plan to support a transition relates to a process to plan for improvements to or replace a TMS.

PLANNING FOR TRANSITIONING A TMS

Some agencies may not be accustomed to conducting assessments or planning for conducting or supporting TMS transition activities. The checklists of questions in chapter 2 can be used as a starting point to begin to organize the issues related to planning for and developing a plan to conduct or support a transition:

- Table 1. Software, databases, and IT checklist.
- Table 2. Staffing and organization checklist.
- Table 3. Business processes checklist.
- Table 4. Departmental and agency collaboration checklist.
- Table 5: Performance monitoring checklist.

Depending on the type of transition, identifying clear public-facing performance measures that support investment in dollars and staff effort to conduct the transition can be challenging.

Initial activities for agencies to consider when planning a new TMS, or improving, upgrading, or replacing an existing TMS, are conducting feasibility studies for the system and its existing and desired future capabilities, subsystems, and components. Feasibility studies may include the following elements:

- **Piloting individual functions without full integration.** Recognizing that improving, revising, replacing, or planning a new system could apply to any system component and does not necessarily mean that the entire system has to be enhanced at once. Agencies may elect not to deploy a completely new system due to constraints such as lack of resources or may elect to pilot a new function along a specific corridor, road facility, or district; recognizing that enhancements to specific components of a TMS allow an agency to improve incrementally and at a feasible pace. Pilot deployments are a relatively low-cost way to identify potential benefits of new functionality.

- **Considering interoperability with existing systems.** Updating specific aspects of a TMS could include subsystems (e.g., software, computing, data); user interfaces; field components or devices; expanded areas of service; enhanced operational strategies, services or functions of the system; and other possibilities. Agencies should consider the requirements to implement these changes in any TMS feasibility study, improvement planning, or transition planning.

- **Articulating risks and potential technical challenges.** Use the checklists in chapter 2 and provided in table 6 to guide the risk assessment. A variety of stakeholders with different areas of technical expertise who may have a role with supporting the TMS might be appropriate to engage (particularly IT professionals and software specialists) when identifying technical risks and issues to address in a transition plan.

- **Considering new operational strategies, functions, actions, and services.** Some TMS functions and actions may be effectively demonstrated through integration of the software with a virtual representation of a TMS. Many agencies may already have such models available at the microscopic, mesoscopic, and/or macroscopic scale to simulate the management and control of traffic on different types of roadways. Microscopic models, in particular, frequently have APIs that can be used to interface the model with TMS functions. Agencies should take care to consider the construction of new models for a feasibility assessment; the cost and time necessary to replicate a specific application geography can easily exceed the cost of piloting the TMS function on an existing simulation. Models also can conveniently estimate many TSMO metrics that are much more difficult to obtain in the real world, such as total travel time, greenhouse gas reductions, and surrogate measures of safety.

Tactical feasibility assessment typically also includes a gap analysis. Taken together with the checklists in chapter 2, the gap analysis for the transition to a next-generation TMS, new TMS, or new TMS subsystem may include the following technical topics:

Table 6. Gap analysis checklist.

Questions	Complete?
How does our existing software operating environment dictate (or not dictate) what technologies we can consider for the next generation? If we need to use alternative operating systems, do we have the skills or abilities to support such systems? Do we need those skills and abilities in-house, or can we rely on support from suppliers? • Many next-generation tools and technologies leverage open-source software operating systems, such as Linux. • Open-source operating systems does not equate to "free." Many agencies find extreme value in purchasing open-source tools from resellers that provide installation, maintenance, and support functions. • Use of proprietary operating systems and applications is not "wrong." Many agencies find value in purchasing proprietary tools from resellers that provide installation, maintenance, support, and upgrade services.	☐
How does our existing data management environment dictate (or not dictate) what data management technologies we can consider for the next generation? Are we heavily invested in proprietary databases? Do we use open-source tools? If we need to use alternative data management tools, do we have the skills or abilities to support such systems? Do we need those skills and abilities in-house, or can we rely on support from suppliers? • Open-source databases does not equate to "free." Many agencies find extreme value in purchasing open-source tools from resellers that provide installation, maintenance, and support functions. • Use of proprietary databases is not "wrong." Many agencies find value in purchasing proprietary tools from resellers that provide installation, maintenance, and support functions. • Database management is complicated and extremely important for effective applications. • Database technologies have evolved rapidly, and continue to evolve, in the era of big data.	☐

Questions	Complete?
How does our existing hardware operating environment (on-premise and/or cloud) dictate (or not dictate) what computing resources we can consider for the next generation? If we need to use alternative hardware, do we have the skills or abilities to support such systems? Do we need those skills and abilities in-house, or can we rely on support from suppliers? • Virtualized hardware is becoming extremely common. • Cloud-hosted systems may be more expensive than purchasing dedicated hardware; the equipment and the support are leased. • On-premises hardware requires skilled staffing to maintain the equipment.	☐
How do our existing software tools dictate (or not) what technologies we can consider for the next generation? If we need to use alternative software, do we need to use alternative suppliers? How will tools from alternative suppliers work together, or not? Do we care if they work together? • Open-source software does not equate to "free." Many agencies find extreme value in purchasing open-source tools from resellers that provide installation, maintenance, and support functions. • Use of proprietary software is not "wrong." Many agencies find extreme value in purchasing proprietary software tools that provide installation, maintenance, and support functions. • Agency-owned software (work made for hire) may allow agencies to hire different developers later to enhance or expand software. In practice, this is extremely difficult to accomplish cost effectively. • Browser-based software is becoming more and more capable, but desktop (installed) applications still have some inherent advantages.	☐

<table>
<tr><th>Questions</th><th>Complete?</th></tr>
<tr><td>How does our existing center-to-field (C2F) communications operating environment dictate (or not dictate) what applications and functions we can consider for the next generation? If we need to use alternative C2F communications, do we have the skills or abilities to support such systems? Do we need those skills and abilities in-house, or can we rely on support from suppliers?
Cost of high-speed, agency-owned wireless continues to drop.
Cost of agency-owned fiber plant continues to drop.
Cost of fourth-generation (4G)/fifth-generation (5G) cellular wireless continues to drop, although these technologies have recurring leasing costs.
Copper interconnect can be converted to IP with low-cost converters.</td><td>☐</td></tr>
<tr><td>How does our existing C2C communications operating environment (on-premises and/or cloud) dictate (or not) what communications technologies we can consider for the next generation? If we need to use alternative C2C communications tools, do we have the skills or abilities to support such systems? Do we need those skills and abilities in-house, or can we rely on support from suppliers?

Sophistication and ease of use of APIs continues to mature.</td><td>☐</td></tr>
<tr><td>How does our existing operational coverage area (on-premises and/or cloud) dictate (or not) what operational strategies we can consider for the next generation?</td><td>☐</td></tr>
<tr><td>How does our existing field device operating environment (on-premise and/or cloud) dictate (or not) what field devices we can consider for the next generation? Do we have an “open” system? Do we use standard protocols? Are we constrained by certain external factors, such as legacy decisions on cabinet types, form factors, and other infrastructure investments?
Standardization of field devices on specific supplier models is not “wrong” but carries inherent risk (vendor goes out of business, discontinues support, raises prices).
Use of standard protocols is encouraged but may limit functionality available in proprietary features of certain devices.</td><td>☐</td></tr>
<tr><td>How do our existing operations business processes influence how we use and apply software and hardware tools? Have we built software TMS around our operations business processes, or are our processes constrained by the functions of existing tools? Is the next-generation TMS a new process, a new tool, or both?</td><td>☐</td></tr>
</table>

Questions	Complete?
How do our existing maintenance business processes influence how we use and apply software and hardware tools? Have we built software TMS around our maintenance business processes, or are our processes constrained by the functions of existing tools?	☐
How do our existing staffing and support resources influence how we use and apply software and hardware tools? Have we built software TMS around our staff, or are our staff constrained in their abilities by the functions of existing tools? Does the next-generation TMS require new process, new staff, retrained staff, or all of the above?	☐
How do our existing cybersecurity processes influence how we use and apply software and hardware tools? Have we built software TMS around our cybersecurity processes, or are our processes constrained by cybersecurity policies and procedures? Threat vectors to agency-owned systems and networks continue to expand.	☐
How do our existing procurement methods and processes influence how we use and apply software and hardware tools? Are we constrained by our procurement methodologies to innovate to the next generation (e.g., restrictions on alternative procurements such as SaaS, PaaS, equipment leasing, etc.)?	☐
How do our existing privacy and data protection processes influence how we use and apply software and hardware tools? Do we need new policies?	☐
How do our existing sources of data influence how we use and apply software and hardware tools? Have we built software TMS around our available data? If new data were available, could our existing processes take advantage of it? Is the next-generation TMS with new data sources a new process, a new tool, or both? Third-party data sources continue to expand in availability. Over time, costs may drop with more competition. Consider long-term implications of purchasing data from others. Can the additional cost be offset by reductions in need for field device maintenance or installation?	☐
How do our existing intra-agency and interagency coordination processes influence how we use and apply software and hardware tools? Have we built software TMS around our abilities or lack of abilities to coordinate with partner agencies, or are our abilities to coordinate with partner agencies constrained by the functions of existing tools? Is the next-generation TMS a new coordination process, new tools, or both?	☐

INTANGIBLES TO CONSIDER WHEN TRANSITIONING A TMS

As discussed in the previous section, many common tactical issues are appropriate to consider in transitioning, regardless of the type of TMS function or system. Agencies also may be facing such questions across many system functions simultaneously. Transitioning to the next generation or a new TMS is not only about capabilities and performance but also benefit/cost analysis and the intangible impacts and considerations on the agency workforce (staffing/ training), IT environment, and other operational issues (e.g., repair, maintenance). Transition plans have many nuances that are not only related to system functionality, software, and attractiveness of GUIs. Decisions related to expanding, extending, upgrading, replacing, and retiring systems and functions are multifaceted and include the following aspects:

- **The reliability of our current software and hardware support suppliers.** How have they performed for us in the past? How likely are they to be acquired, merged, liquidated, or discontinue business operations? How frequently have support staff turned over? If we have not received adequate support in the past, were our expectations out of touch with what we were willing to pay?

- **The grass is always greener syndrome.** New software may look shiny and attractive but may be no more useful to our operations than our existing applications. Upgrading or extending existing systems, even giving systems a complete "facelift," may be an order of magnitude less expensive than replacement.

- **Things work this way because they've always worked this way.** Some business processes tend to evolve over time into complicated activities based on accumulation of small adjustments based on short-term ideas, new policies, or other requirements. Asking "why" is sometimes helpful to unravel if a system or process really needs to be as complicated as it currently is. If new ways of doing something are unlocked through technology, maybe the time is now to retire the old way of accomplishing an end goal and transition to another workflow with a new TMS or subsystem.

- **The critical question of whether to integrate or not.** It is usually true that TMS with functionality to control, command, monitor, and analyze multiple field device systems create synergies and opportunities for the next generation of a TMS or subsystem. On the other hand, device suppliers are usually better positioned to support their own equipment. Standards and protocols to exchange and use data may exist to bridge these gaps, but replacing siloed functions with an integrated software is not always the least costly alternative.

- **Detailed transition planning considerations for systems that are used only occasionally but are mission critical when they are needed.** Testing and verification of new functionality for life-safety, disaster response, and other niche functions can become complicated and costly, quickly. Existing systems may have legacy interfaces and protocols that may not be readily available. An agency may be inclined to transition everything at once but may not like the resulting costs and schedule for mission-critical but legacy systems.

- **Back-end components that are working but are no longer compliant with IT policies should be assessed for risk.** Network security is an important element of the modern IT landscape, and many older TMSs may have vulnerabilities. Other IT policies, such as those for transitioning from a database using proprietary information and data formats to a database using open-source software and data formats, may reduce maintenance cost over the long run but may incur substantial costs to replace such technologies with no observable impact on user effectiveness or system capability. Databases are particularly impacted; while SQL is a common standard, many proprietary extensions of SQL exist that may be used in software to improve performance or reduce code needed through shortcut features of a particular back-end system.

- **Frequently used systems that currently present a high level of manual workload to produce a result are the best candidates for early transitioning.** Software and related automation technologies that free up humans from mundane tasks have high return on investment, and not only in monetary terms.

- **A common triage strategy is replace upon failure.** Legacy software systems have embedded dependencies on system components or devices that will eventually become unsupported. Computing hardware and components such as power supplies and hard drives will eventually fail. From a cost perspective, waiting until these elements eventually fail is an attractive idea, perhaps by obtaining discontinued parts such as hard drives or power supplies from used equipment retailers along the way. Transition planning before the eventual failure should be considered in such cases, particularly if the TMS or subsystem is mission critical.

- **New device types and support for legacy protocols.** Retaining older device types might be preferable for consistency of maintenance or software compatibility. However, extending an existing function or component (e.g., ramp metering) to a new or updated TMS, subsystem, or location (e.g., corridor) might not make more sense; for example, a new controller, a newer low-voltage cabinet, or high-speed communications may be applicable, which could result in changes needed to the software and design of the component. Adding new devices in a new area may be less complicated than disrupting existing communications and operations in an area that is currently online. Adding new device types may require support within existing software, which may be considered; or new software may be vetted with the new equipment to evaluate the transition to a new platform in a controlled manner.

PROCESS, REQUIREMENTS, AND ISSUES WHEN TRANSITIONS INCLUDE PROCUREMENT

In most cases, transitioning to a new or updated TMS or subsystem may involve procuring hardware or software. Agencies that are planning for a transition may wish to consider the following items when planning for these procurements:

- **Consider designs and specifications that minimize the articulation of very specific GUI operations.** If the existing system uses a “drop down” or a “right-click menu,” resist the urge to require candidate suppliers to carbon-copy replicate existing modalities of accessing information.

- **Consider designs and specifications that provide detailed information for particularly complex operations.** The current incumbent supplier probably understands why something works a specific way, but other candidate suppliers do not have that institutional history and knowledge. Just because a new supplier misinterprets what has been written in the request for proposal document does not mean they are incapable of fulfilling the requirements.

- **Provide as many details as possible on what legacy equipment, devices, software (e.g., manufacturer, model) will be kept in operation.** This item is similar to the previous issue. Candidate suppliers do not have the institutional history with an agency's operations, and they will likely ask many questions regarding legacy devices, protocols, interfaces, and business processes. If these details are not provided, new suppliers must estimate these costs based on very little information, resulting in their cost estimates being much higher than necessary. Alternately, suppliers may vastly underestimate the complexity of integration with legacy components, resulting in downstream disagreements about scope and fee.

- **Consider procurement specifications that are oriented toward "show me what you have."** Articulation of specific functionality may be difficult to achieve in the concept of the operations stage. The agency may be more interested in procuring the capability to do something but is not particularly prescriptive in the way a function should look or feel. Suppliers that have already implemented a function with a particular workflow can demonstrate alternative manners to achieve the same objective.

- **Include requirements for delivery of an acceptance test plan, testing, and extensive acceptance testing verification.** The new supplier should provide evidence that the new TMS or subsystem is satisfying agency requirements for a replacement or new TMS or subsystem. The acceptance test plan articulates how the functionality will be verified. Acceptance testing usually has two components—(1) an acceptance test "event" where all the test plans are executed by the supplier and agency together, and (2) an acceptance "burn in" period where the TMS or subsystem is operated for some time without failure. Issues commonly surface after the acceptance test "event" is concluded, and testing some edge-case scenarios with simulated or sample data can be difficult.

- **Consider transition in phases.** The initial phase may be the deployment of the base functionality with what the supplier can provide based on their current capabilities. The supplier can use future phases to customize the functionality for the agency's specific needs. One potential drawback to this approach is that some suppliers may propose a very low-cost solution to "get in the door," expecting that the future will bring substantial change orders.

- **Provide a cost-proposal template that is reasonably detailed.** Carefully planned requirements and scope of work for a transition project can be easily offset by an overly simple cost-proposal template. Collapsing hundreds of thousands to millions of dollars of software licenses, software development, hardware, integration services, support, maintenance, and documentation into just a handful of rows in a cost-proposal table can considerably impede an agency's ability to compare proposals "apples to apples." When multiple subsystems are involved in a transition, consider listing each subsystem element as a line item in the cost-proposal table. The more detailed a cost-proposal table becomes, the less chance for potential suppliers to misunderstand or misinterpret what costs should go where. In addition, a detailed breakdown of level of effort can assist the agency in determining the priority of elements in a transition project. Visibility into the costs for integration or replacement of each subsystem helps to make clear what parts are more difficult to accomplish than others.

Costs for TMS Transitions

Automation and computer systems have reduced the human capital requirements in specific roles but have increased the number of functions and oversight required of each TMS operator. Agencies face a larger recurring cost associated with daily operations of the TMS and recurring maintenance costs associated with increased features/equipment. These costs include both internal costs for staffing and training for the agency and the costs of vendor and supplier support for software and hardware. Most traditional procurements of software and hardware for TMSs have been provided by the supplier and included proprietary products and a combination of the following items:

- Fees for field devices, physical or virtual servers, and existing software licenses.
- Labor costs for project management, installation, configuration, testing, customization, and acceptance.
- Fees for software development and implementation of new original modules or functions.
- Fees for support to operations, warranty, software/hardware maintenance, and cloud hosting.

Support, Maintenance, Warranty, and Hosting

When planning for any improvements to TMSs, an agency should consider the costs to manage, operate, and maintain a TMS and what it can provide in funding. An understand of the expected costs for subsystems, components, and devices will assist agencies with decisions made in planning, designing, or procuring improvements to the TMS. How the agency plans to provide the resources should be considered in these processes. Additional issues to consider when procuring these improvements and transition plan include the following:

- **Support** generally describes the vendor effort, either on a fixed-price or time-and-materials basis, for hours spent to assist the agency in configuration, operation, and troubleshooting.
- **Warranty** generally describes the vendor's commitment to repair or remedy failed software and hardware. While determining that a hardware component has failed is relatively straightforward, separating troubleshooting from warranty repair in software systems can be difficult. Many hours of troubleshooting may reveal that the issue initially considered to be a "bug" in the TMS software is an artifact of incorrect configuration or an impact from an ancillary process, such as a security scan or a firewall rule.

- **Maintenance** generally describes the vendor effort to keep the hardware or software running smoothly. For hardware, maintenance may include routine checkups, cleaning filters, and replacement of components. Maintenance for software may include optimization of database settings, replacement of components for new software standards, and adjustments to software operations for new security patches, firewall rules, or operating system changes.

- **Hosting** generally describes vendor costs to supply virtual computing resources, databases, and related software services for the TMS in a cloud system. Some TMS can be hosted on a variety of cloud providers, while others may be tied to a specific platform based on use or integration of specific components.

Some issues to consider in costs for support and maintenance of transitioning TMS include the following:

- **Consider carefully the response times and on-call time for support and warranty requests.** While agencies may aim for an immediate 24 h/365 d response from vendors and suppliers, such requirements can be vastly more expensive than agreements that require responses during business hours. While traffic is indeed an ongoing occurrence, the on-call costs for overnight, rapid-response support can vastly exceed their actual use in practice. Also, consider time zones when selecting software and hardware suppliers. Vendors outside of the United States, or vendors that have offshore support staff, also may have very different working hours than your agency.

- **Consider carefully what responsibilities are assigned to the supplier and to the agency for determining failure conditions.** Many issues with software operation may be attributable to agency equipment failures (switches, cut fiber) or ancillary system outages (agency VPN is down, an agency C2C service may have stopped sending data, etc.) that are not the responsibility of the supplier. This discovery process can be a complex back-and-forth between agency staff and TMS supplier staff. Liquidated damages associated with failures or downtime can make these interactions contentious.

- **Consider carefully how agency IT activities impact supplier software systems.** Changes to security settings are a common contributor to "random" TMS application failures. Agencies should coordinate new IT policies, vulnerability scans, and other important security actions with software suppliers, as functions may become inoperable, and troubleshooting can be more straightforward with effective, proactive communication. Agencies should coordinate additional activities such as moving API endpoints, renaming servers, reallocating virtual machine specifications, and other routine IT actions with TMS software suppliers.

- **Consider the trade-offs of cloud hosting versus on-premise deployment.** Many software providers now offer their TMS solutions as a service. Where an initial fee may be lower, the ongoing leasing of the software tends to be higher each year than traditional procurements when the agency owns the software for perpetual use, with on-premise hardware. Some agencies now consider cloud-first deployment policies of new software procurements; many new security and privacy concerns are invoked when agency data (in whatever form) now resides in a secondary location (i.e., the vendor's cloud tenancy), the data are still subject to agency security policies, but the agency has difficulty in directly configuring the implementation of such policies. Some agencies now manage their own cloud tenancy, so it may be worth exploring if the vendor-supplied software for a TMS may be installed in an agency-managed cloud, where the agency has direct control over the hosting of the software and costs.

Staffing Capability Impacts on Transitions

Operating an increasingly sophisticated TMS requires trained staff who have the knowledge and skills to operate and maintain the TMS. The more knowledgeable internal IT support staff are with the new technologies (databases, cloud platforms, APIs, protocols, networking configuration, etc.), the smoother the transition. Agencies should consider the following staffing issues when transitioning to next generation of TMSs:

- **Consider identifying dedicated IT resources for the transition project.** Identifying IT resources to be a part of the team responsible for the development of a transition plan, procurements, and the actual improvement is a critical step. IT support works directly alongside the team during all stages of the transition, including planning, design, procurement, development, implementation, testing, and shift to operation.

- **Consider carefully which responsibilities are assigned to the supplier and to the agency to solve and address development, testing, acceptance, and initiation of operations related issues.** The contractor may be much more skilled at deploying hardware and equipment during the transition, but eventually, agency staff may be expected to deploy such equipment without contractors onsite. Do not underestimate the value of training early in the transition process.

- **Consider building up resources over time who understand the underlying technologies being deployed.** Specialized resources in data science, artificial intelligence, and other related fields are probably not necessary in the early stages of transitions. However, having a resource—even a contracted subject matter expert—as the project matures can be helpful to assist in interpreting results and findings during the transition period. When in doubt, develop written documents that describe technology characteristics, workflow, protocols, and the like. Relying on certain staff to provide this knowledge resource is risky because people retire/resign, get reassigned, or become unavailable for a variety of other reasons.

FEASIBILITY ASSESSMENT OF TMS TRANSITIONS

The checklists in the preceding sections provide the basis for assessing the feasibility and the resources that may be needed to support a TMS transition. Generally, a feasibility assessment for a TMS transition answers questions regarding the following:

- The specific issues being experienced with the existing TMS and TMS subsystems.
- The rationale that the transition to a new version or replacement system or subsystem will resolve the specific issue(s).
- Existence of a transition solution, or 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., end of support for an operating system or software platform, discontinued product models, new protocols or standards).
- Testing plan, acceptance testing, documentation and acceptance of testing, and responsibilities of contractors and agency.

In some cases, the agency may include the feasibility assessment in a procurement for a TMS improvement. Proposals for performance of the work may propose a transition plan within the resources specified, or the proposed plan and activities may be included in a contract proposal. Another option is a request for information (RFI) to garner feedback from suppliers and contractors on the feasibility of a TMS transition.

In other cases, the feasibility assessment need not be a detailed and lengthy process. The assessment could involve technical workshops, meetings, or be a task included in a planning effort or an improvement project where the transition plan is a product, developed in-house or by a contractor, accepted by the agency. The transition plan may include the findings (in addition to summarizing responses to RFIs, if used) to support the development of a transition plan, and obtain the resources needed to support a transition.

SUMMARY

Chapter 3 discussed issues related to tactical planning for a TMS transition. Taken with the checklists in chapter 2, the topics in chapter 3 are important considerations for assessment of the feasibility, cost, schedule, and risks of a transition, which include the following:

- Identification of the objectives and outcomes of the transition.
- Analysis of the gaps between current operation and systems and the next-generation TMS.
- Consideration of intangibles such as current and future supplier support, contracting mechanisms and IT policies, obsolescence risks, security, and the level of future integration desired or required.
- The procurement processes, methods, and terms and conditions.
- Terms and conditions of support, warranty, maintenance, and licensing.
- Agency staffing and organization during the transition process.

Assessment of transition feasibility need not be a lengthy process, but consideration of all the topics listed in chapters 2 and 3 will lead to a more favorable outcome. While “gotchas” can arise when the transition is formally underway, feasibility assessment in advance will uncover many of the pain points with much less future complication.

With these issues in mind, chapter 4 will discuss the necessary and desirable features of a tactical transition plan.

CHAPTER 4. ELEMENTS OF A TMS TRANSITION PLAN

INTRODUCTION

This chapter outlines the typical elements of a transition plan. The transition plan's complexity may be proportional to the scope and scale of the improvement being contemplated and the transition being considered. For example, upgrading an existing component to a new component with limited added capabilities or functions may not require an extensive transition plan nor agency resources to support the effort. On the other hand, wholesale replacement of a TMS with a new TMS may involve extensive articulation of the issues, process, activities to be performed, plans to be developed (e.g., test plan, acceptance plan), and resources needed to support the activities and the agencies overseeing the transition.

This chapter discusses the following topics:

- Typical elements of a transition plan.
- How might a transition plan vary based on the activities to be performed.

TRANSITION PLAN

After the agency has determined that a transition is warranted and feasible, a transition plan can improve the probability of success during implementation, ensuring the improvements function as designed and that the desired transition occurs as planned. A transition plan should include the activities to be performed in support of transitioning from the current operation to the next system. The transition plan should include the following:

- **Articulation of the "why"**—Goals and objectives for the transition. These goals or objectives are *not* societal benefits such as reducing travel time or improving safety but rather the desired outcomes of the transition plan to ensure the development, implementation, testing, acceptance, and initiation of the operation of the TMS as planned. These goals could include the following:
    - Remove dependency on physical on-premise hardware.
    - Upgrade back-office operations to a modern, supported operating system.
    - Provide the capability for corridor-wide ramp metering.
    - Reduce the cost of obtaining a data service.
- **Articulation of the "what"**—Functions, services, actions, and subsystems to be transitioned. The plan should identify, in as much detail as possible, what specifically needs to be done to achieve the transition. The following list provides some examples:
    - Implementing support for ramp meter version 1.6.1.
    - Backing up existing databases.
    - Moving API endpoints from X to Y.
    - Revising firewall rules for services.
    - Creating VPN and user accounts.

  - Configuring new virtual servers or server clusters.
  - Installing applications and service dependencies.
  - Configuring cloud services and security.
  - Creating a test plan, including tests that can be accomplished by demonstration and tests that require a duration of operation (such as "burn in' testing which requires an extended length of time to be conducted).
  - Disconnecting field devices from the legacy TMS and connecting devices to the new TMS.

- **Articulation of the "how"**—Details of activities to accomplish the list of items in the scope of work (the "what"). In the systems engineering process, a ow-level design document(s) (i.e., a document with detailed design specifications) is developed. While certain funding sources and processes may require detailed documentation in an agile manner, close collaboration among the team is a better method to address detailed design than communicating knowledge transfer through writing. Strike a balance that makes sense for the project. If the project is relatively straightforward, less detail is usually required. If the operation of a mission-critical tunnel ventilation control system is being moved from a legacy solution to a new supplier, for example, strive for extreme detail. Often, one or two experts will have a great deal of institutional and technical knowledge related to a specific service, function, or subsystem. Take the time to gain as much technical information from these experts into the transition plan as possible in case they are no longer available (retire, resign, reassigned, sickness, etc.) during the transition process. In-person meetings (including virtual) are often more effective than relying on email exchanges when discussing technical transition issues. Video/audio recordings of such knowledge transfer may be useful as well. A risk register also may be helpful to identify potential points of complexity. In addition to low-level design document(s), the team should establish methods of communication to gauge progress (weekly meetings, email updates, document collaboration sites, etc.).

- **Articulation of the "who"**—Groups and persons (preferably individual names) responsible for leading tasks and accomplishing activities. In particular, IT activities can involve a variety of persons and usually scales up as the organization's size becomes larger. As much as possible, the agency should assign responsibilities for various activities identified in the scope of work ("what") to specific persons. As articulated in the "how" section, pay close attention to key personnel and experts that have unique knowledge and skills necessary for the success of the transition. Difficult interpersonal issues also can arise during transitions, particularly if institutional knowledge resides within a current supplier that is being replaced by another supplier. Overlap of support contracts may serve to smooth the transition but may not be practical.

- **Articulation of the "when"**—The schedule and dependency of activities on downstream work. Dependencies of one task on others are particularly important during a complex transition, including interdependencies among activities. Be prepared to be flexible with schedules as unknown challenges may arise. Developing and resolving schedules as a team in an open and collaborative manner is important, as is booking time and resources as far in advance as possible and being cognizant of life events for team members (vacation, maternity leave, etc.).

Regardless of the due diligence applied during the feasibility analysis stage, software transitions may exhibit many unknown complexities and unforeseen challenges. An Agile approach to such issues is warranted during the transition.

APPENDIX: TRANSITION ISSUES FOR SPECIFIC TMS FUNCTIONS

The checklists presented in the previous sections outline the types of questions relevant to any TMS application or upgrade effort. In this section, some next-generation capabilities of TMS functions are identified to guide IOOs toward the gaps that need to be addressed to convert legacy and/or existing TMS to next-generation functions.

INCIDENT AND EVENT MANAGEMENT

Incident management includes queue detection, verification, incident response, onsite monitoring, and active management. Incident management is a common function of State DOT TMSs but much less common in arterial TMSs. Incident management is most commonly an "operator in the loop" staff-intensive activity in coordinating with law enforcement and first responders, freeway service patrols, and towing service providers. Innovations in incident detection technologies are emerging, but business processes have not changed substantially in recent years. Decision support systems can bolster the next generation of incident management, including the use of artificial intelligence and machine learning to help generate incident response plans (signal control plans, CMS messages, ramp metering rates, lane control displays, speed limits or advisories, etc.). Video analytics (artificial intelligence-based detection of vehicles from streaming videos) also is a next-generation technology for improving incident management.

Table 7. Incident management checklist.

Questions	Complete?
What are the strengths of our existing software for incident management?	☐
What are the weaknesses of our existing software for incident management?	☐
What additional hardware might be required to transition our existing software?	☐
Should we replace or augment our existing incident management software? How configurable is our current software to adjust incident management workflows?	☐
Would additional field equipment or systems improve our incident management processes (ATM, drone surveillance, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspaces) to transition incident management to the next generation?	☐
Do we need additional staffing to transition incident management to the next generation?	☐
Do we need different staffing (field crews, TMC operators, road rangers, drone operators, etc.) to transition incident management to the next generation?	☐
Are our business processes and software workflows for incident management cumbersome? Could these weaknesses be addressed through software configuration, or is replacement/transition necessary?	☐

Questions	Complete?
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning incident management to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our incident management process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or public-private partnerships (PPP)?	☐

Road Hazard and Speed Warnings

Many State DOTs have specialized warning systems for road hazards and speed warnings, high winds, weather-related surface conditions, truck escape ramp monitoring, and other specialty warning systems, most of which operate locally via CMS and/or flashers. Arterial TMSs are not commonly used for such purposes. Innovations could include connectivity of the status information to vehicles directly (via roadside equipment (RSE) or app), improvements in detection technology (radar, light detection and ranging (LiDAR), weather sensors), and enhancements of detection capabilities from data from vehicles instead of infrastructure (via RSE or app).

Table 8. Road hazard and speed warning checklist.

Questions	Complete?
What are the strengths of our existing software for road hazard warnings?	☐
What are the weaknesses of our existing software for road hazard warnings?	☐
What additional hardware might be required to transition road hazard warnings to the next generation?	☐
Should we replace or augment our existing road hazard warnings software? How configurable is our current software to adjust road hazard warning workflows? Can we create new triggers? Can we combine multiple inputs to form more complex logic?	☐
Would additional field equipment or systems improve our road hazard warning processes (sensors, artificial intelligence-based video detection, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspaces) to transition road hazard warnings to the next generation?	☐
Do we need additional staffing to transition road hazard warnings to the next generation?	☐
Do we need different staffing (field crews, TMC operators, road rangers, drone operators, etc.) to transition road hazard warnings to the next generation?	☐
Are our business processes and software workflows for road hazard warnings cumbersome? Could these weaknesses be addressed through software configuration, or is replacement/transition necessary?	☐

Questions	Complete?
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning road hazard warnings to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our road hazard warnings process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Traffic Signal Operations

Almost all State DOTs operate both traffic signals and freeway management devices, although few agencies have integrated systems that do both. Many IOOs have operators that are focused on one or the other, but again, not both. Local agencies (counties, cities, townships, etc.) typically operate traffic signal systems and CCTV surveillance on arterial roads. Most agencies have some CMS on arterials, both fixed and portable, and a handful of local agencies have some responsibilities or capabilities to manage freeway-related devices and operations. Innovations in traffic signal operations include the emergence of a variety of methodologies for the following:

- Automated traffic signal performance measures (ATSPM).
- Software-based transit-signal priority and emergency vehicle preemption.
- More cost-effective adaptive control options.
- Integration of traffic signal operations with other device management such as CMS, ramp metering, and C2C data sharing.
- Coordinated incident response across agency jurisdictions.
- Dynamic lanes and reversible lanes on arterials and at traffic signals.
- Arterial work zone management.

Many agencies are currently considering automated generation of time-of-day timing plans using machine learning and artificial intelligence with ATSPMs. Integration of connected vehicle hardware and software is also an emerging area of focus for arterial management and traffic signal control operations. Arterial operations departmental responsibilities vary widely across IOOs in the United States, with some agencies having additional responsibilities for management of publicly operated parking facilities and enforcement, street lighting, and other related infrastructure such as high-water warning detection.

Table 9. Traffic signal operations checklist.

Questions	Complete?
What are the strengths of our existing software for traffic signal operations?	☐
What are the weaknesses of our existing software for traffic signal operations?	☐
What additional hardware might be required to transition traffic signal operations to the next generation? New communications? Different communications? New controllers? Different controllers? More detection? Different detection?	☐
Should we replace or augment our existing traffic signal operations software? How configurable is our current software to adjust traffic signal operations workflows?	☐
Would any additional field equipment or systems improve our traffic signal operations processes (lane controls, reversible lanes, drone surveillance, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspaces) to transition traffic signal operations to the next generation?	☐
Do we need additional staffing to transition traffic signal operations to the next generation? Signal timing engineers? Field technicians? Communication specialists?	☐
Do we need different staffing (data scientists, IT specialists, etc.) to transition traffic signal operations to the next generation?	☐
Are our business processes and software workflows for traffic signal operations cumbersome? Could these weaknesses be addressed through software configuration, or is replacement/transition necessary?	☐
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning traffic signal operations to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our traffic signal operations process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Freeway Ramp Metering

Most State DOTs that operate TMCs have some ramp metering management functions. Most ramp metering currently operates on time-of-day schedules with fixed metering rates or with locally traffic-responsive rate algorithms. Corridor ramp metering methods are used by some agencies and is becoming more common. Many agencies express the desire to coordinate ramp meter operations with adjacent traffic signal operations. Innovations in next-generation TMS may include the following:

- Feeding ramp metering systems with alternative data sources (crowdsourcing, connected vehicles, third-party APIs) as infrastructure in-pavement sensors continue to be phased out.
- Coordinating ramp meters in a corridor.
- Coordinating ramp metering rates with adjacent interchange traffic signals.
- Implementing bypass operations for buses and emergency vehicles.
- Holding ramp meters in red when buses or public safety vehicles are using the adjacent freeway shoulder.

Table 10. Freeway ramp metering checklist.

Questions	Complete?
What are the strengths of our existing software for ramp metering?	☐
What are the weaknesses of our existing software for ramp metering?	☐
What additional hardware might be required to transition ramp metering to the next generation? New controllers? Better communications? New detection?	☐
Should we replace or augment our existing ramp metering software? How configurable is our current software to adjust ramp metering workflows for incident response, coordinated operations for corridors, or coordinated operations with adjacent interchanges?	☐
Would any additional field equipment or systems improve our ramp metering processes (ATM, detection, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspaces) to transition ramp metering to the next generation?	☐
Do we need additional staffing to transition ramp metering to the next generation?	☐
Do we need different staffing (field crews, TMC operators, data scientists, drone operators, etc.) to transition ramp metering to the next generation?	☐
Are our business processes and software workflows for ramp metering cumbersome? Could these weaknesses be addressed through software configuration, or is replacement/transition necessary?	☐

How involved are my existing private-sector vendors, suppliers, and consultants in transitioning ramp metering to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our ramp metering process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Managed Lanes

Variable speed limits, lane control signs, and convertible high-occupancy vehicle/high-occupancy toll lanes are gaining in popularity at State DOTs. Such systems are less common for arterial management agencies, but a fair number of local municipalities do operate such systems for controlling egress/ingress to event venues such as stadiums and highly directional traffic facilities. As ATM continues to gain in popularity, particularly in locations where building additional capacity is not an option, innovations in managed lane operations will continue to challenge TMSs to upgrade their capabilities for the next generation.

Table 11. Managed lanes checklist.

Questions	Complete?
What are the strengths of our existing software for managed lanes?	☐
What are the weaknesses of our existing software for managed lanes?	☐
What additional hardware might be required to transition managed lanes software to the next generation? CMS formats? Full-color displays? Computing power? RSEs?	☐
Should we replace or augment our existing managed lanes software? How configurable is our current software to adjust managed lanes workflows?	☐
Would any additional field equipment or systems improve our managed lanes processes (connected vehicle applications, apps, new CMS displays, integrated displays)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspaces) to transition managed lanes software to the next generation?	☐
Do we need additional staffing to transition managed lanes software to the next generation?	☐
Do we need different staffing (field crews, TMC operators, road rangers, data scientists, etc.) to transition managed lanes software to the next generation?	☐
Are our business processes and software workflows for managed lanes cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐

Questions	Complete?
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning managed lanes software to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our managed lanes process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

CMS Displays

CMS operations are a cornerstone of most State DOT operations and many larger arterial operations agencies. Many DOTs are transitioning from matrix displays to full-color, fully graphical capabilities that provide a host of additional functions, such as ATM displays in all lanes with one sign. Virtual CMS warnings are emerging with data feeds to third parties that disseminate the information to their users (e.g., navigation apps, connected vehicles, 511 apps). Automated generation of sign messages (crash one mile ahead, crash two miles ahead, etc.) are an element of many next-generation strategies for rapid-response incident management, as is the ability to send messages to many signs at once, schedule messages, and diagnose sign malfunctions easily.

Table 12. CMS display checklist.

Questions	Complete?
What are the strengths of our existing software for CMSs?	☐
What are the weaknesses of our existing software for CMSs?	☐
What additional hardware might be required to transition CMS operations to the next generation? Full-color displays? More capable display processors/ controllers?	☐
Should we replace or augment our existing CMS software? How configurable is our current software to adjust CMS workflows?	☐
Would any additional field equipment or systems improve our CMS processes (full matrix color/graphics, drone surveillance, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspace) to transition CMS operations to the next generation?	☐
Do we need additional staffing to transition CMS operations to the next generation?	☐
Do we need different staffing (field crews, TMC operators, road rangers, drone operators, etc.) to transition CMS operations to the next generation?	☐
Are our business processes and software workflows for CMSs cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐

Questions	Complete?
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning CMS operations to the next generation? Are there barriers to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our CMS process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Work Zone Management

Most agencies struggle to maintain a current and accurate list of real-time work zone activities, particularly on arterials since so much work is done on arterials that is not the direct responsibility of the traffic management functions of the agency (water main repairs, utility services, etc.). Work zone data exchange 3.0 standards are now available[(6)], but challenges still remain for populating work zone data through automated means. TMS operations for work zone management could be greatly enhanced with emerging technologies, including connected vehicles, third-party data feeds, and intradepartmental data sharing (smart cities).

Table 13. Work zone management checklist.

Questions	Complete?
What are the strengths of our existing software for work zone management?	☐
What are the weaknesses of our existing software for work zone management?	☐
What additional hardware might be required to transition work zone operations to the next generation?	☐
Should we replace or augment our existing work zone management software? How configurable is our current software to adjust work zone management workflows?	☐
Would any additional field equipment or systems improve our work zone management processes (connected cones, flashers/beacons, driver feedback signs, drone surveillance, connected wearables for workers, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspace) to transition work zone operations to the next generation?	☐
Do we need additional staffing to transition work zone operations to the next generation?	☐
Do we need different staffing (field crews, TMC operators, road rangers, drone operators, etc.) to transition work zone operations to the next generation?	☐
Are our business processes and software workflows for work zone management cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐

Questions	Complete?
How already involved are my existing private-sector vendors, suppliers, and consultants in transitioning work zone operations to the next generation? Are there barriers to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our work zone management process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Traveler Information

Most State DOTs operate traveler information systems and many supplement agency infrastructure traffic detection with third-party data feeds. Many (usually larger) arterial management agencies also provide such services in their regions, depending on regional responsibilities; particularly in large States (California, Texas, etc.). Innovations to 511/traveler information functions could include personalized, geofence information for connected travelers or enhanced data sharing with third parties (e.g., Navigation apps' "unusual traffic," work zones, transit system status). While many traveler information functions are provided by third parties (e.g., navigation apps.), many status elements can only be provided by IOOs.

Table 14. Traveler information system checklist.

Questions	Complete?
What are the strengths of our existing software for traveler information?	☐
What are the weaknesses of our existing software for traveler information?	☐
What additional hardware might be required to transition traveler information management to the next generation?	☐
Should we replace or augment our existing traveler information software? How configurable is our current software to adjust traveler information workflows?	☐
Would any additional field equipment or systems improve our traveler information processes (ATM, drone surveillance, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspace) to transition traveler information management to the next generation?	☐
Do we need additional staffing to transition traveler information management to the next generation?	☐
Do we need different staffing (field crews, TMC operators, data scientists, drone operators, etc.) to transition traveler information management to the next generation?	☐

Questions	Complete?
Are our business processes and software workflows for traveler information cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐
How already involved are my existing private-sector vendors, suppliers, and consultants in transitioning traveler information management to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our traveler information process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Congestion Pricing, Tolling, and Commercial Vehicle Operations (CVO)

Toll operations are typically managed separately from other State DOT TMS functions, although such functions are becoming more integrated, particularly with the commonality of tag-free tolling via license plate. As congestion pricing (cordon line) and road user fee concepts continue to emerge, new innovations in TMSs and integration between toll systems and advisory/control systems will be needed as will integration of tolling and congestion pricing with connected vehicles. Weigh-in-motion and commercial vehicle parking management are common functions of TMS for CVO.

Table 15. Congestion pricing, tolling, and CVO checklist.

Questions	Complete?
What are the strengths of our existing software for congestion pricing and tolling?	☐
What are the weaknesses of our existing software for congestion pricing and tolling?	☐
What additional hardware might be required to transition congestion pricing, tolling, and CVO management to the next generation?	☐
Should we replace or augment our existing congestion pricing and tolling software? How configurable is our current software to adjust congestion pricing and tolling workflows?	☐
Would any additional field equipment or systems improve our congestion pricing and tolling processes (ATM, CMS, video analytics, drone surveillance, connected vehicle applications, apps)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspace) to transition congestion pricing, tolling, and CVO management to the next generation?	☐
Do we need additional staffing to transition congestion pricing, tolling, and CVO management to the next generation?	☐

Questions	Complete?
Do we need different staffing (field crews, TMC operators, road rangers, drone operators, etc.) to transition congestion pricing, tolling, and CVO management to the next generation?	☐
Are our business processes and software workflows for congestion pricing and tolling cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐
How already involved are my existing private-sector vendors, suppliers, and consultants in transitioning congestion pricing, tolling, and CVO management to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our congestion pricing and tolling process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Performance Measurement

Data analytics is becoming a more common element of existing TMSs. Legacy systems are more likely to be augmented with performance measurement and analytics systems, but with minimal integration. On the arterial side, particularly with the emergence and interest in ATSPMs, new systems for performance analysis are becoming available commercially as well as developed as open-source systems by State DOTs. Many challenges are emerging, such as the storage and management of the data itself and the capabilities and availability of staff to perform the analytics and studies. Automation of many performance monitoring functions may emerge in the next generation to relieve staff time and effort to view reports. Optimization of TMSs follows from measurement of performance, so this TMS function feeds back into almost every element described earlier.

Table 16. Performance measurement checklist.

Questions	Complete?
What are the strengths of our existing software for performance measurement?	☐
What are the weaknesses of our existing software for performance measurement?	☐
What additional hardware might be required to transition performance measurement processes to the next generation? Databases? Storage? Processing power?	☐
Should we replace or augment our existing performance measurement software? How configurable is our current software to adjust performance measurement workflows?	☐
Would any additional field equipment or systems improve our performance measurement processes (sensors, drone surveillance, connected vehicles, apps, third-party data sources)?	☐

Questions	Complete?
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, smartboards, workspace) to transition performance measurement processes to the next generation?	☐
Do we need additional staffing to transition performance measurement processes to the next generation?	☐
Do we need different staffing (data scientists, artificial intelligence specialists, software developers, etc.) to transition performance measurement processes to the next generation?	☐
Are our business processes and software workflows for performance measurement cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning performance measurement processes to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our performance measurement process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

Device Maintenance

Very few TMSs have a holistic view of device maintenance needs across all agency asset types, even within a given department (e.g., ramp meters, traffic signals, communication plant, and CMS may be in separate databases and tracked by different technologies). Innovations in software and business processes for device maintenance management may greatly improve TMS operations and public service. Device maintenance management also goes hand in hand with performance measurement functions.

Table 17. Device maintenance checklist.

Questions	Complete?
What are the strengths of our existing software for device maintenance management?	☐
What are the weaknesses of our existing software for device maintenance management?	☐
What additional hardware might be required to transition device maintenance management processes to the next generation? Bar code scanners? Quick response (QR) code scanners? Drones? LiDAR?	☐
Should we replace or augment our existing device maintenance software? How configurable is our current software to adjust device maintenance workflows?	☐

Questions	Complete?
Would any additional field equipment or systems improve our device maintenance processes (bar codes, QR codes, drones, connected vehicle applications, automated vehicle data feeds, LiDAR scanners, etc.)?	☐
Do we need changes to our physical facilities (workstations, video wall(s), ticker displays, workspace) to transition device maintenance management processes to the next generation?	☐
Do we need additional staffing to transition device maintenance management processes to the next generation?	☐
Do we need different staffing (field crews, TMC operators, drone operators, data scientists, etc.) to transition device maintenance management processes to the next generation?	☐
Are our business processes and software workflows for device maintenance cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning device maintenance management processes to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our device maintenance process could potentially be improved through automation? Artificial intelligence and machine learning? Outsourcing or PPPs?	☐

TMS DATA SHARING AND INFORMATION EXCHANGE

Most existing TMSs have some elements of data sharing and information exchange. Data sharing can range from automated software feeds of real-time status with regional or local partners to downloadable samples of IOO datasets for the public. Data exchange software and protocols have evolved rapidly with new technology standards for formatting and sharing data through the Internet using widely supported API formats (JavaScript Object Notation (JSON))[(7)]. Similarly, data lakes and related transformational data processing tools and platforms have enabled the merging and harmonization of data from different sources in different formats much easier than was possible even just 5 yr ago. Security of API-to-API communication now is mostly standardized with public key infrastructure encryption technology based on Internet standards. Next-generation TMSs will largely be able to accept data and provide data in any standard API format with limited cost and development effort.

Table 18. TMS data sharing and information exchange checklist.

Questions	Complete?
What are the strengths of our existing software for data sharing and information exchange?	☐
What are the weaknesses of our existing software for data sharing and information exchange?	☐
What additional hardware might be required to transition data sharing processes to the next generation? Newer operating systems? different operating systems? Firewalls?	☐
Should we replace or augment our existing data sharing and information exchange software? How configurable is our current software to adjust data sharing and information exchange workflows?	☐
Would any additional field equipment or systems be needed to support transition data sharing processes to the next-generation exchange processes (C2C fiber connections? Firewalls and gateways? Higher-bandwidth Internet connections?)?	☐
Do we need changes to our physical facilities (rack space, servers, workstations, video conferencing) to transition data sharing processes to the next generation?	☐
Do we need additional staffing to transition data sharing processes to the next generation?	☐
Do we need different staffing (data scientists, software developers, IT networking) to transition data sharing processes to the next generation?	☐
Are our business processes and software workflows for data sharing and information exchange cumbersome? Could these weaknesses be addressed through software configuration, or is replacement necessary?	☐
How involved are my existing private-sector vendors, suppliers, and consultants in transitioning data sharing processes to the next generation? Do barriers exist to engaging additional private-sector vendors, suppliers, or consultants in some capacity as part of a next-generation TMS pilot? What are those barriers?	☐
What parts of our data sharing and information exchange process could potentially be improved through automation? Outsourcing or PPPs? SaaS subscriptions?	☐

REFERENCES

1. Kuciemba, S., L. Jacobson, A. 2023. Mizuta, and D. Nguyen. *Review of Traffic Management Systems—Current Practice*. Report No. FHWA-HRT-23-051. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-23-051.pdf, last accessed February 7, 2024.

2. Lamb, E. 2020. "Georgia DOT Wins Transportation Management and Operations Award." *Transport Topics*, September 15, 2020. https://www.ttnews.com/articles/georgia-dot-wins-transportation-management-and-operations-award, last accessed March 27, 2023.

3. URS Corporation. 2011. *Regional Traffic Operations Program Concept of Operations*. Atlanta, GA: Georgia Department of Transportation. https://cdn.atlantaregional.org/wp-content/uploads/2011-gdot-rtop-con-ops.pdf, last accessed March 27, 2023.

4. AASHTO/ITE/NEMA. 2023. *National Transportation Communications for ITS Protocol Object Definitions for Actuated Signal Controllers (ASC) Interface*. NTCIP 1202 Version 03B. Washington, DC: AASHTO; Washington, DC: ITE; Rosslyn, VA: NEMA. https://www.ntcip.org/file/2024/02/NTCIP-1202v03.35e-aspublished.pdf, last accessed February 9, 2024.

5. Virginia Information Technologies Agency. 2018. *Information Technology Resource Management (ITRM)—Cloud-based Hosting Services for IT Solutions Policy*. ITRM Policy EA 300-01. https://townhall.virginia.gov/L/GetFile.cfm?File=C:%5CTownHall%5Cdocroot%5CGuidanceDocs%5C136%5CGDoc_VITA_7313_v1.pdf, last accessed February 15, 2024.

6. FHWA. 2023. "Work Zone Data Exchange" (web page). https://www.transportation.gov/av/data/wzdx, last accessed February 9, 2024.

7. IBM. 2024. "JavaScript Object Notation (JSON) format" (web page). https://www.ibm.com/docs/en/baw/22.x?topic=formats-javascript-object-notation-json-format, last accessed February 9, 2024.

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