# Practices for Improving the Coordination of Information Technology and Transportation Systems Management and Operations Resources:

# A Reference Document

*June 2022*

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

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**16. Abstract**

The document provides the transportation operations community (public agencies, consultants, and researchers involved in planning for, designing, operating, and maintaining transportation operations and management systems) with information on practices in coordinating with information technology staff. This material focuses on the value of coordination and collaboration between operations staff and information technology staff.

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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 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9<br>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 (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| $cd/m^2$ | $candela/m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | $lbf/in^2$ |

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

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| | |
|---|---|
| AI | Artificial intelligence |
| AST | Agency for State Technology |
| ATM | Active traffic management |
| CAV | Connected and autonomous vehicle |
| CCTV | Closed-Circuit Television |
| CFR | Code of Federal Regulations |
| CIO | Chief Information Officer |
| CMM | Capability Maturity Model |
| DOT | Departments of Transportation |
| DOTD | Department of Transportation and Development |
| DSS | Decision Support Systems |
| DTMB | Department of Technology, Management and Budget |
| FDOT | Florida Department of Transportation |
| FHWA | Federal Highway Administration |
| ICM | Integrated corridor management |
| ICS | Industrial Control System |
| IEEE | Institute of Electrical and Electronics Engineers |
| IGA | Intergovernmental agreement |
| IoT | Internet of Things |
| IP | Internet Protocol |
| IT | Information Technology |
| ITS | Intelligent Transportation System |
| KSA | Knowledge, skills, and abilities |
| LADOTD | Louisiana Department of Transportation and Development |
| MOU | Memorandum of understanding |
| NIST | National Institute of Standards and Technology |
| NOCoE | National Operations Center of Excellence |
| OT | Operational Technology |
| OTS | Office of Technology Services |
| OTT | Office of Transportation Technology |
| PennDOT | Pennsylvania Department of Transportation |
| PMI | Project Management Institute |
| PTC | Pennsylvania Turnpike Commission |
| TDOT | Tennessee Department of Transportation |
| TMC | Transportation management center |
| TSMO | Transportation Systems Management and Operations |
| V2I | Vehicle to Infrastructure |
| V2X | Vehicle to Everything |

# EXECUTIVE SUMMARY

The role of information and communications technology is increasingly central to Transportation Systems Management and Operations (TSMO), as leading-edge TSMO strategies involve ever more complex and interrelated systems, organizations, and institutions. Real-time and predictive TSMO strategies, such as active traffic management (ATM), integrated corridor management (ICM), and vehicle-to-infrastructure (V2I) systems, are complex and depend on integrating information technology (IT) into TSMO strategies.

This document highlights the benefits of increased coordination between TSMO practitioners and IT resources, identifies common challenges experienced by public-sector agencies, and presents practices that allow agencies to learn from others that have already addressed similar challenges. The specific purpose of this document is to:

- Describe the evolution and history of TSMO and IT within typical transportation agencies and the current organizational relationship.
- Identify common challenges experienced within TSMO relative to the IT resources required to implement operational strategies.
- Identify practices that transportation agencies have developed and implemented to resolve IT challenges.
- Develop a solution matrix that links the common challenges to these practices for ease of reference.
- Provide information on using these approaches toward emerging IT-related TSMO issues.

The advancement of technology has expanded significantly over the past decades and has created significant opportunities within all aspects of life, including Government agencies. The increased computing capability, infrastructure connectivity, data collection and analysis, and remote or web-based platforms have all contributed to new capabilities. Within public agencies, adoption and use of technology has increased in recent years as the public comes to expect increased functionality and convenience resulting from technology-based systems. These technology systems no longer provide ancillary support functions but provide critical aspects of an agency's mission.

The increased use of technology from customers both internal and external to transportation agencies requires agencies to develop a robust IT support level that can develop, manage, and protect the systems. While technology costs continuously drop per given application, the overall investment remains high and presents a large asset for agencies. To protect their capital investment and ensure proper function, agencies often find it critical to have advanced technical expertise to maintain the systems and ensure seamless operation.

Key aspects of typical TSMO programs that utilize technology include traffic surveillance, vehicle detection, traveler information, traffic management centers, road weather sensors, and traffic signals among many other functions. These systems need hardware maintenance, software support, network IT, and communication knowledge, and generate significant amounts of data. IT staff can support TSMO programs in these areas.

Many agencies and organizations are experiencing similar challenges when it comes to the intersection of TSMO and IT while operating their transportation systems. These challenges can include disconnects, misunderstandings, and points of conflict on program priorities, risks, and differences in standards. This document includes a discussion of 36 specific challenges grouped into the following categories:

- **Institutional Challenges:** Any challenge—from leadership decision-making to frontline implementation—that is encountered at all levels of the organization. The interaction between TSMO staff and IT staff is often influenced by the organization itself, including professional culture, organizational structure, staff capabilities, and resource allocation.
- **Culture:** Any challenge that develops from the values and behaviors that influence personal relationships or interactions between the differing agency functions and groups.
- **Staff and Financial Resources:** Any challenge that results from the availability, recruitment, retention, and training of staff or the availability, justification, and use of funding, both of which are critical components to fulfilling agency-identified needs.
- **Organizational Structure:** Any challenge that develops from the formal and informal structural arrangements around the management of staffing, roles, and responsibilities.
- **Policy:** Any challenge that results from legislation, executive-level directives, departmental policy, or requirements that are not directly related to TSMO or are outside the departments or divisions of either IT or TSMO.
- **Business and Technical Challenges:** Any challenge encountered at any stage of project activity or development. Implementing technology within an agency can be impacted by the business and technical processes associated with developing systems, including planning, procurement, security and data, and new, technology-specific challenges.
- **Strategic Planning:** Any challenge that develops from the vision, mission, and objectives of the different organizations or functions and their integration in agency planning and resource allocation.
- **Procurement:** Any challenge that results from the processes and procedures associated with obtaining IT-intensive products or services.
- **Systems and Technology:** Any challenge that involves the hardware and software components of data acquisition, management, and utilization technologies.
- **Risk and Security:** Any challenge that is associated with network security, data sharing, third-party applications, hosted or cloud platforms, and automation.

As agencies respond to and resolve their TSMO IT challenges, they develop practices that can be shared with other agencies experiencing similar issues. This document includes discussion of 28 specific practices.

Finally, the transportation industry is experiencing a period of significant growth in technology development and adoption. While some of the emerging technologies are still being tested for viability and business need, foreseeable trends include reliance on edge computing, distributed

hardware and networks, cloud-based services, mobile access, connected and autonomous vehicle (CAV) integration, and a general exploration of vehicle-to-everything (V2X) communication.

While there is no way to know what these future developments will be, it is likely that they will include more reliance on technology and data, which will have impacts on both IT and TSMO groups individually, and their interactions with the other. Several practices are included in this effort that agencies can use to form a solid foundation for IT and TSMO collaboration ahead of emerging technologies, or to address challenges encountered when implementing emerging technologies.

# CHAPTER 1. INTRODUCTION

## DEFINITIONS

Terminology changes and has different uses in different sectors and among various agencies. For purposes of this the document, the following definitions are adopted:

- **Transportation Systems Management and Operations (TSMO)—**"Integrated strategies to optimize the performance of existing infrastructure through (i) the implementation of multimodal and intermodal, cross-jurisdictional systems, services, and projects designed to preserve capacity and improve security, safety, and reliability of the transportation system; and (ii) the consideration of incorporating natural infrastructure." (23 U.S.C. 101(a)(32)). For purposes of this project, TSMO is seen as not just applying strategies, but also the supporting processes, centers, data sources, and institutional arrangements supporting their sustainability and continuous improvement.
- **Information Technology (IT)—**For purposes of this project, IT refers to back-end hardware and software, data sources, networks and agency-wide (or enterprise) software and systems, such as email, web applications, and financial systems.
- **Operational Technology (OT)—Hardware and** software that "detect or cause a direct change through the monitoring and/or control of devices, processes, and events." (National Institute of Standards and Technology (NIST) Glossary). For purposes of this project OT refers to the front-end, field-based devices used to provide detection, surveillance, monitoring and operational control.
- **Industrial Control System (ICS)—**"An information system used to control industrial processes such as manufacturing, product handling, production, and distribution. Industrial control systems include supervisory control and data acquisition systems used to control geographically dispersed assets, as well as distributed control systems and smaller control systems using programmable logic controllers to control localized processes." (NIST Glossary.) This definition of ICS applies throughout this document.
- **Intelligent Transportation Systems (ITS)—**"ITS applies information, technology, and systems engineering principles to the management and operations of surface transportation facilities and systems, including freeways, arterials, and transit. It provides numerous benefits to transportation." (ITS ePrimer). For purposes of this project, ITS refers to the technology that supports many TSMO strategy applications.
- **TSMO Strategies—**Combinations of "ITS information and control communications infrastructure with related field procedures and protocols within a specific operational concept designed to anticipate and mitigate the impacts of the various causes of congestion." (American Association of State Highway and Transportation Officials TSMO Guidance). For purposes of this project, TSMO strategies include applications such as ramp metering, incident management, freeway operations, ATM, and integrated corridor management.
- **Agency—**Transportation agencies with units focused on transportation systems development, maintenance, and operations. These include State departments of transportation (DOT), regional transportation agencies, and local transportation agencies.

- **IT Group—**IT professionals who may be part of a Statewide IT entity, an IT staff unit within transportation agencies, or any mix thereof.

## BACKGROUND

IT has always played a role in TSMO, strategy by strategy and in multi-strategy control systems, such as advanced transportation management systems. However, the role of information and communications technology is becoming increasingly critical to TSMO, because leading edge TSMO strategies involve ever more complex and interrelated systems, types of information, organizations, and institutions. Real-time and predictive TSMO strategies, such as ATM, integrated corridor management (ICM), and vehicle-to-infrastructure (V2I) systems, are characterized by high levels of complexity and a dependence on integrating IT into TSMO strategies. It is important to address these issues from both a transportation and IT perspective to find the best approaches and organizational arrangements to operate and maintain these systems.

The advancement of technology—including increased computing capability, infrastructure connectivity, data collection and analysis, and remote or web-based platforms—has contributed to new capabilities of State DOTs to improve TSMO and provide higher levels of service and improved effectiveness, efficiency, safety, and reliability. These systems no longer provide ancillary support functions, but provide critical support to an agency's mission, and TSMO has become a large adopter of advanced technology. Key aspects of typical TSMO programs that utilize technology include traffic surveillance, vehicle detection, traveler information, traffic management centers, road weather sensors, and traffic signals, among many other functions. As new products and services are developed to support the TSMO mission, transportation agencies continually evolve to take advantage of the technology. And while technology costs continuously drop per given application, the overall investment remains high and represents a large asset for agencies. In addition, the technology presents an increased potential for threats posed by cybersecurity breaches in an increasingly connected world. To protect capital investment, and to ensure proper and secure function, TSMO programs increasingly depend on robust IT support that can develop, manage, and protect the systems.

The expanding role of IT and IT policy at the agency-wide level intersects with information technology and information systems across a wide range of State Government agencies, of which transportation agencies and their TSMO programs are only one way to create a range of common opportunities and challenges. Opportunities include the ability to collaborate, leverage respective skill sets, and gain advantages in procurement and maintaining IT infrastructure. Challenges include disconnects, misunderstandings, and points of conflict on program priorities, risks, and potential difference in standards. Even small challenges between these groups can lead to bigger hurdles as the levels of reliance increase, and there is a greater need for each group to understand the business requirements of the other. Many agencies have developed practices that address the challenges experienced between TSMO and IT groups.

## TRANSPORTATION PERSPECTIVE

Agency TSMO-functions aim to maximize the efficiency, safety, and reliability of the existing transportation infrastructure through operational strategies rather than through physical expansion. These strategies incorporate a wide range of organizational, engineering, and operational efforts, both internal and external to an agency. Newer and more complex TSMO systems present significant challenges to transportation agencies, including:

- Device costs and varying lifecycles.
- Expanded number and diversity of devices, many of which are very specialized.
- Hardware and software specification, standardization, and procurement.
- "Big data" acquisition development, management, and storage.
- Data transparency and security.
- Connections to external entities, both public and private.
- Device and system durability requirements.

Increasingly, these issues require IT professionals to develop, manage, and protect the growing communication networks, datasets, equipment, and other technological aspects that support the operational goals of the agency.

## INFORMATION TECHNOLOGY PERSPECTIVE

Some of the larger State Departments of Transportation (DOT) often have their own IT staff, sometimes including a Chief Information Officer (CIO) responsible for administering the agency's data and IT resources. The DOT CIO may also interface with issues related to network security and data access control, which sometimes intersect with TSMO systems development, especially regarding procurement.

However, the increasing role of IT across the public sector has led to a pervasive information technology administrative presence throughout all State Government agencies. The extent of the IT focus is reflected by the fact that all States, U.S. territories, and the District of Columbia have a State-level CIO, according to the National Association of State Chief Information Officers. The State CIO responsibilities are becoming more global and their oversight has expanded, as reflected in national IT organizations, such as the National Association of State Chief Information Officers and the National Association of State Technology Directors.

TSMO strategies and ITS represent examples of OT. OT is defined as hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes, and events. There can be challenges or issues between offices or groups responsible for OT and those responsible for IT, including challenges of governance and oversight versus carrying out operational objectives in an effective and efficient way.

## TSMO AND INFORMATION TECHNOLOGY INTERFACE

The IT TSMO discussion often focuses on IT-related components of TSMO regarding issues related to standardization, procurement, cost control, external partners, lifecycles and redundancy, security and control, and other matters. At the Statewide level, the dominant issues are security, cost control, and budget, with special attention to the emerging concerns regarding cloud services, data management and governance, broadband commitment, artificial intelligence, net neutrality, and converging digital infrastructures. Given the pervasive nature of these issues across State agencies, it is not surprising that the IT function is increasingly formalized and centralized at the Statewide level, including IT functions within transportation agencies (and TSMO units).

The relationship between transportation operations and IT has been challenging, especially since the introduction of computerized traffic management systems. IT staff often have priorities that differ from TSMO staff, and therefore, may not appreciate their perspectives and responsibilities. Likewise, TSMO staff often do not appreciate the perspectives and responsibilities of IT staff. The lack of understanding often results in conflict between the two groups and inefficiencies in the work of both.

This conflict is not unique to transportation. In other sectors, there is also a difference in perspective between IT staff and staff responsible for industrial control systems (ICS). ITS and TSMO monitoring and control systems are examples of OT, as the same as ICS in manufacturing, energy distribution, and water distribution. According to the Global Sign Blog, one of the concerns from an OT perspective is that "IT teams generally have little experience with industrial systems."

The conflicts in ICS became so pronounced that concerted efforts have been made to bring the IT perspective and the OT perspective together. This effort is called IT/OT convergence. Several websites that focus on ICS have articles and webpages focusing on IT/OT convergence. (Examples include Industrial IoT World, Internet of Business, and D!gitalist Magazine.)

A significant portion of the effort in IT/OT convergence is to promote understanding between the two groups. Cybersecurity topics can also point out the differences in perspective between IT and ICS. A Department of Homeland Security document (Recommended Practice: Improving Industrial Control System Cybersecurity with Defense-in-Depth Strategies) includes a table that compares security functions between IT and ICS. Many of these differences are like those between IT and TSMO in the transportation sector. In a similar vein, table 1 in chapter 2 of this document compares differences between TSMO and IT environments in transportation to promote common understanding between TSMO staff and IT staff.

Considering the above issues and dynamics, this project provides a comprehensive review of common challenges associated with the increased interaction between TSMO and IT and presents practices that can be utilized to counter those challenges.

## PURPOSE

The development of this reference document highlights the need for increased coordination between TSMO practitioners and IT staff to support the management and operations of transportation assets. The range of available TSMO strategies that rely on technology are

continually increasing in size and complexity and require stronger organizational and technological resources. This document allows agencies to learn from others who have already encountered similar challenges and developed practices.

The purpose of this document is to:

- Describe the evolution and history of TSMO and IT within typical transportation agencies and the current organizational relationship.
- Identify common challenges experienced within TSMO relative to the IT resources required to implement operational strategies.
- Highlight practices that transportation agencies have developed and implemented to resolve IT challenges.
- Develop a solution matrix that links the common challenges to these practices for ease of reference.
- Provide suggestions on using these approaches toward evolving and emerging ITS issues.

This document focuses on the interaction between TSMO and IT. This interaction takes place within the context of TSMO activities in State DOTs and other transportation agencies.

## METHODOLOGY

As TSMO remains relatively new in many agencies, there are limited formal or traditional resources on the interaction between TSMO and IT, and fewer on effective methods to manage challenges. However, the industry's increased focus on TSMO initiatives and available technology has resulted in increased interaction between IT staff and TSMO staff, and agencies have individually responded in ways that are both common and unique. Therefore, most of the research effort focused on agency interviews and interactive workshops to identify challenges and practices that applied to the development of this guidance document.

A brief description of the major research efforts is provided below.

### Literature Review

The project team performed a review of available document resources with a focus on IT and TSMO, including Federal, State, and association publications that provide background information on transportation agency functions and needs, especially those that refer to IT. Sources that did include IT were typically focused on either data management or a narrowly defined, issue-based research topic.

### State of the States

Evaluating the existing organizational structure of State agencies was based on web-based agency information and interviews to provide a high-level understanding of the various structures under which TSMO and IT staff and units—Statewide and within transportation agencies—function, and how those structures may impact the interaction.

### Capability Maturity Model Workshops

A review of past TSMO Capability Maturity Model (CMM) workshops was conducted to identify IT-related issues raised by participants. The insights from these self-assessments provided an agency-level perspective and identified key agencies for follow-up discussions. Strengths and weaknesses related to IT from each CMM dimension were used as reference examples.

### Practitioner Interviews and Correspondence

Targeted interviews were conducted with agencies that had practices identified through the literature and workshop material or otherwise believed to have extensive TSMO efforts with significant IT involvement. The focus of the interviews was to obtain details relative to the issues or challenges they face, lessons they have learned, and practices they have implemented.

### Input from Listening Sessions

Two formal listening sessions were facilitated by the team to generate discussion between practitioners. The sessions focused on eliciting input on IT experience in TSMO programs from agency representatives in a group setting with the opportunity to share among peers.

## STRUCTURE AND USE OF REPORT

This document serves as a reference to assist public agencies with strengthening TSMO and associated IT resources. It is intended for TSMO leadership and practitioners, as well as IT leadership and practitioners, and provides background and guidance from both perspectives. While the number of stakeholders may be wide-ranging, the primary document users are anticipated to be:

- TSMO and IT leadership—Responsible for high-level organizational decisions.
- TSMO and IT program managers—Responsible for program-level initiatives.
- TSMO and IT project professionals—Responsible for project-level delivery.

The key focus of this document is the description and analysis of the common challenges to effectively coordinating IT and TSMO and identifying practices that experience suggests could mitigate the same challenges. In many cases, more than one practice can address a given challenge, so a matrix tool was developed to highlight the range of applicability. A practitioner who wishes to address challenges related to IT and TSMO coordination, interaction or interface can look through the matrix categories and locate the specific challenge or set of challenges of interest and the correlated practices to mitigate that challenge. For each practice listed in the matrix, more detail is provided in appendix B. Conversely, as any given practice may address multiple challenges, a practitioner may also wish to know what other challenges the selected practices may address. Appendix C contains a matrix that displays the set of challenges that each practice could address.

The organization of the document provides an introduction followed by the primary guidance tool, with most of the detail and methodology as supporting material. Chapter structure is as follows:

- **Chapter 1: Introduction**

  This chapter provides an overview of the document purpose and goals, the evolution of TSMO and IT, and the business case for increased coordination between IT and TSMO within transportation operations. The chapter also highlights the research methodology and document structure.

- **Chapter 2: The Context and Benefits of Information Technology and TSMO Coordination**

  This chapter discusses the history and evolution of the interaction between TSMO and IT and provides agency examples developed from the outreach efforts. The chapter explains why this topic is critical to transportation operations and performance.

- **Chapter 3: Challenges of Information Technology and TSMO Coordination and Related Practices**

  This chapter discusses how agencies can apply practices to specific known challenges in their organization. An application matrix—the principal tool contained in this document—is presented for use in identifying appropriate practices for given challenges or conditions.

- **Chapter 4: Applying TSMO and Information Technology Interaction Principals to Emerging Issues**

  This chapter presents how the underlying principals associated with the practices identified in chapter 3, and described in more detail in appendix B, can be applied to new or emerging challenges.

  The focus of this chapter is on creating flexibility to meet unknown issues and minimizing risk or impact through targeted efforts.

- **Appendix A: Common Challenges**

  Appendix A describes the common challenges identified from the research, organized into sections by topic area and categorized into two large classes—business or technical challenges and institutional challenges. Included along with the challenge descriptions are real-world examples of agency challenges that highlight typical situations.

- **Appendix B: Identified Practices**

  Appendix B synthesizes the practices identified from the research and is organized into sections by topic area. Both general practices and more specific tactics are within each topic. Numerous real-world examples of these practices are provided.

- **Appendix C: Applicability of Identified Practices**

  Appendix C presents a reference matrix that is the inverse of the matrix tool in chapter 3. This matrix allows agencies to identify the range of challenges that each practice can address.

# CHAPTER 2. THE CONTEXT AND BENEFITS OF INFORMATION TECHNOLOGY AND TSMO COORDINATION

This chapter describes the importance of IT and TSMO coordination in the context of public-sector transportation agencies. A brief history of IT and TSMO development and evolution within transportation agencies highlights the differences in approach and function that may influence the current environment, while an examination into the overlapping technology highlights the benefit of continued coordination. The chapter concludes with a table and discussion summarizing what agencies have determined to be beneficial for IT staff to know about TSMO, and what they have determined to be beneficial for TSMO staff to know about IT. The table and discussion provide context to many of the subsequent common challenge and identified practice discussions in the remainder of the document.

As the transportation industry continually evolves to take advantage of the emergence of new technologies and incorporating technology in all aspects of agency business, there is increasing interaction between TSMO programs and IT oversight and support functions. These interactions reflect a dual role for many IT organizations. IT organizations support TSMO and Intelligent Transportation System (ITS) technology and communications efforts, and they may also have an oversight and approval role for certain aspects of TSMO and ITS technology implementations, particularly for security and procurement. With these additional interactions, agency staff have identified a greater need for each group to understand the business requirements of the other.

IT departments or offices generally have two primary roles: protecting and regulating IT assets and providing customer service for groups needing IT support. This dual role underscores why some agencies have identified the importance of IT organizations to understand the wide range of business requirements across a transportation agency, particularly for programs with such engrained need for technology as TSMO and ITS. Similarly, the rapid evolution of technology overall and in procuring technology supporting services and agency needs for cybersecurity protection, illustrate the importance of TSMO and ITS groups better understanding both the role of centralized IT groups and the valuable resources they can provide to the operational mission of transportation agencies. A mutual lack of understanding between IT and TSMO reflects a traditional difference in culture between the two groups. The difference in culture is reflected throughout the functions of the organization, including business management, transportation program management, managing devices and assets, and operations management (including both traffic and maintenance operations as well as public safety and emergency response operations). More discussion of common understanding between TSMO Staff and IT staff is presented in the section "Point of Departure: Difference Between TSMO and Information Technology Environments."

In transportation agencies, there are evolving customer expectations of technology and tools, from both internal and external customers, as well as increased concerns over potential threats that are posed by cybersecurity breaches in an increasingly connected workplace. The potential threats are posed to both organizational enterprise IT applications (like email or access to the web) and internal business systems. Because of these threats and the need to cost-effectively

procure technology that will meet the wide-ranging needs of transportation agencies, agencies emphasize providing centralized expertise and oversight to protect technology investments and services and to support the operational mission of public agencies.

## HISTORY OF INFORMATION TECHNOLOGY IN TRANSPORTATION AGENCIES

The dual role of IT organizations (protecting and regulating IT assets and providing customer service for groups desiring information technology support) and the increasing number of technology solutions deployed by TSMO organizations led many agencies to recognize the importance of mutual understanding between IT and TSMO groups. This mutual understanding is somewhat hampered by the way each group developed. The role of IT within transportation agencies has evolved over time as ITS evolved from an early traffic management focus to the more complex multiple strategies of TSMO. This evolution includes both its role in back-office business applications, as well as in the systems and technology supporting TSMO strategies themselves.

### Early Information Technology Support of Agency Business Functions

IT groups came into being to develop and support complex agency business applications, such as accounting and personnel management, that were primarily operated offline in "batch" mode by large mainframe computers. While the physical scale of the hardware was large, the processing capabilities were limited to set functions with relatively restricted interfaces. Input was largely done through punch cards, magnetic tape, or simple keyboards. Output was normally stored on magnetic tape or printed. As functionality increased in the late 1970s and1980s, users were able to provide varied input through modular terminals or consoles.

Structured IT resources within transportation agencies developed in earnest as agencies began switching from mainframe computing to personal computers. The adoption of personal computers in the 1980s and 1990s required agencies to decentralize, establish networks, and support a growing number of new software applications. The increased technical resources necessary to manage the new hardware and varied software was significantly greater than in the past and initiated the "information technology" groups that are common today.

### Initial Independence of TSMO Applications

Separate from the above business-based computing, technology directly supporting transportation functions largely developed independently. Initiating and expanding these traffic systems were often completed without direct support of IT resources because the technology was specialized and located within a branch of the organization without high volume business (customer) transactions.

In the 1970s and 1980s, traffic management systems (the precursor to ITS) operated in real-time on microprocessor-based field devices along with centralized mini-computers. Because these systems did not need to integrate into the wider agency technology ecosystem, they often operated on dedicated communication lines and networks entirely independent of other State agency systems. Software packages were also stand-alone. The traffic management systems were often programmed in assembler code and FORTRAN, whereas many of the standard IT applications used for business processes were programmed in business-oriented languages like COBOL.

These differences in devices and applications and the related computing platforms and languages led IT groups and ITS groups within transportation agencies to develop separate networks, equipment, and distinct business practices. The differences also led to separate organizational components with minimal overlap and understanding between IT and ITS staff. Often, staff within one agency's ITS unit did not see value in involving IT staff in a technology project because they did not think that IT staff understood the operations business requirements, especially real-time, 24/7 operations. Rather than educate the IT staff on the ITS units' priorities, the managers developed their own "shadow IT" group within the Operations Division to implement technology projects.

As more sophisticated transportation management systems developed and expanded, transportation agencies started to see the value in integrating systems to share data and provide an integrated user interface to allow multiple systems to be monitored and controlled from a single workstation. The development of ITS placed more emphasis on integrating systems, which led to the development of the National ITS Architecture. The growth of transportation management systems also led to huge growth in the number of field devices that are connected to a central management system. Transportation agencies developed multi-purpose communication networks to provide the connection and the bandwidth to support applications, like transmitting live, full-motion closed-circuit television (CCTV) images. The transportation management communication networks were completely separate from the agency's internal telecommunication networks, which were developed to support increased business needs, like email. IT staff managed the business communication network, and transportation management staff managed the transportation management communication network.

### Increasing Role of Information Technology in TSMO

Today, new technology, big data, and the continuous operation of field devices has turned transportation agencies into heavy IT users. Virginia Department of Transportation (DOT) has identified how IT and TSMO—a specific type of operational technology (OT)—have grown closer together and have significant overlap (figure 1). As the Virginia DOT Director of Technology and Cybersecurity observed, "Unlike the past, many new technologies fall under both IT and OT, further driving the need for convergence between the two."[1]

[1] Murali Rao, "Innovations in ITS Procurement Technology, Software, and Service," Presentation for the National Center of Excellence (NOCoE) Webinar Series, May 7, 2021.

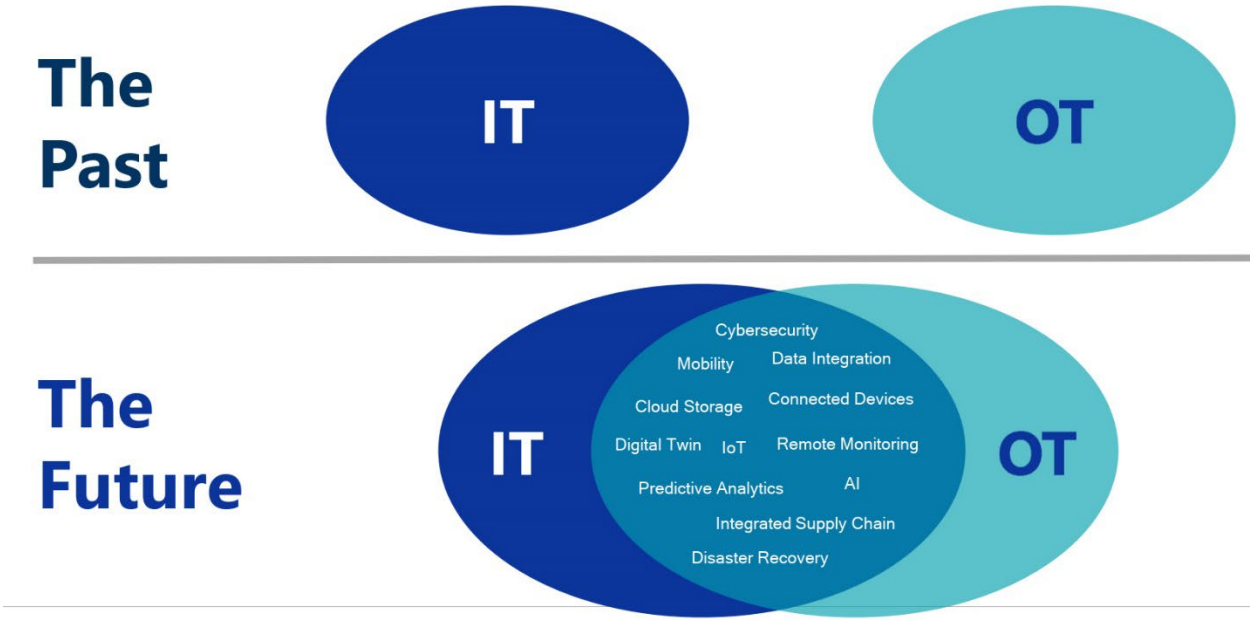


**Figure 1. Venn diagram. The overlap of information technology and operation technology.**
(Source: M. Rao, Virginia Department of Transportation.)

As agencies transition from traditional project-focused agencies to operations-focused agencies, TSMO efforts are becoming more complex and integrated across platforms and jurisdictions. Internal systems are no longer single suites, but a system of systems. A range of changes has led to increased intersection between TSMO and IT, including:

- Advances in TSMO application-specific technology have led to an increasing reliance on agency-owned and operated ITS field equipment.
- Advanced TSMO strategies, such as Integrated Corridor Management and Active Transportation and Demand Management, make heavy demands on decision support systems and associated communication networks and software.
- Extensive deployment of wireless and fiber networks with associated networking equipment.
- Importance of transportation management centers (TMC) where data is collected, transferred, evaluated, and often remotely operated.
- Integration and sharing of crowdsourced data.
- A wider range of data formats from analog to digital, text value to video, periodic to continuous, and so forth.
- External partnerships, developed from data sharing or monetization, and cloud-based computing increase the importance of risk management and cybersecurity.
- Emerging technology and application trends such as reliance on edge computing, distributed hardware or networks, cloud-based services, mobile access, connected and autonomous (CAV) integration, and a general exploration of vehicle-to-everything (V2X) communication.

Taken together, these systems make heavy demands on hardware maintenance, software support, network IT, communication (fiber) knowledge, and other IT-related resources. It is important to consider and understand the hierarchy of importance of various TSMO devices and systems. Moving from isolated devices to linked TSMO systems requiring extensive IT expertise is a spectrum. There is value for agencies to have clarity in thinking through what field assets can be more isolated or stand-alone, which are connected to a main system via a communications network (requiring IT support) but in an observation-only capacity (we can "see" what the ramp meters are doing, but not alter their state remotely), and those that are fully connected for central control and often include data sharing with external organizations (generally requiring extensive IT support). This also relates to cybersecurity and ITS devices and systems. Some devices and systems are more critical than others. An understanding of what is most important for fail-safe operations is key. A loop detector failing is probably not an immediate critical failure, whereas a signal control system or reversible lane control system failure is critical. It is important to understand that there is flexibility and hierarchy of needs for IT resources within the TSMO environment.

For the more complex systems, IT support is crucial. While "shadow IT" staff within a traffic group could support previous ITS elements, advanced strategies and systems are becoming more IT-centric and require a dedicated team of IT professionals for support. As a result, TSMO and IT increasingly intersect and create both opportunities and challenges for increasing cooperation and coordination. Opportunities include the ability to collaborate, leverage respective skill sets, and gain advantages in procurement and maintaining IT infrastructure. Challenges include disconnects, misunderstandings, and points of conflict on program priorities, risks, and potential difference in standards for availability and redundancy for enterprise ITS versus including industrial control systems and supervisory control and data acquisition-type environments.

**Staff Development Challenge**

The overall job market for knowledgeable technology employees is very strong and makes it difficult for public agencies to hire and retain qualified staff. Many States have experienced an increased difficulty in recruiting positions with the multidisciplinary knowledge required in TSMO due to private industry competition and internal human resources constraints.

Available compensation levels offered from one State DOT could not compete with private pay, particularly with the strict position classifications and pay structure required by human resources. While TSMO staff involved with the traffic management center and ITS have identified the need for IT knowledge, the job classifications are included in the broad category of "maintenance," and are not allowed to be advertised as specialists in particular IT areas. The result is that it is very difficult to establish positions that require IT knowledge and even more difficult to establish pay levels that are attractive to people with the necessary IT knowledge and experience.

## POINT OF DEPARTURE: DIFFERENCE BETWEEN TSMO AND INFORMATION TECHNOLOGY ENVIRONMENTS

This project's literature review, workshops, and stakeholder interviews found that improved coordination and collaboration between TSMO and IT is often grounded in a basic understanding of key differences in perspectives, roles, and processes that characterize the differences between

the two disciplines. Until recently, TSMO and IT staff supporting a transportation agency may not have extensive exposure to each other's mission or operational responsibilities. This could be a function of physical location, organizational structure, processes, or lack of opportunity. Regardless of the reason for separation, there is benefit in understanding the general perspectives, roles, and practices of the other group when working together.

### Overcoming Domain Differences

Prior to detailing key challenges, principles, and strategies for improving TSMO and IT coordination and collaboration, it is important to address these differences and identify what staff and management in each group identify as important know about the other's basic views and perspectives. In the following section, selected key differences and similarities are highlighted that crosscut the subsequent discussion of specific challenges presented in subsequent chapters and provide an important background for enhanced mutual understanding. These differences are both institutional in nature (including both general perspectives and roles) and process-related (focusing on certain key practices on each side).

The key differences between TSMO and IT perspectives, roles, and practices have been grouped into six areas:

- Discipline governing principles.
- Domain components.
- Risk management.
- Standards and architecture.
- Devices and assets.
- Future technologies.

There has been some experience to date in overcoming these differences. In the discussion of each area below, some examples from specific agencies are provided to illustrate these differences.

### Discipline Governing Principles

Governing principles reflect the orientation of a discipline and how they are embodied in an organization and its basic practices on a day-to-day basis. For the TSMO professionals, those principles focus on ensuring safe and efficient day-to-day operational control of the transportation network. This requires not only complex application-specific transportation management infrastructure and processes but also interfacing with external players who are key partners in service provision. It is also important to the safety and efficiency of the network that management system elements are available whenever they are needed, regardless of the time of day or day of week. TSMO staff emphasize uptime of transportation management systems and component parts and structure their support to respond accordingly.

The IT role is typically broad based across multiple Government agencies, and functions with communication and information needs. This results in a dual role, providing cost-effective IT

solutions for other business lines or organizations, as well as acting as stewards of IT assets within their jurisdiction. Thus, IT staff may act as service providers to their customer organizations, such as TSMO units, while they must also enforce policies to safeguard the entire enterprise technology environment. These policies typically deal with procurement, securing the communication network, or data governance consistent with standards and practices established at the governmental level. Sometimes these policies do not seem to align with the expeditious conduct of TSMO staff missions. However, it is important for TSMO staff to understand these roles and work with IT staff to find solutions that will comply with both sets of governing principles.

One example of emerging practice is illustrated below by the experience of Florida DOT in clarifying the roles and responsibilities of the TSMO and IT groups.

**Case Study of Florida DOT Practice: Clarify Roles and Responsibilities**

Like many public agencies, the Florida Department of Transportation's (FDOT) TSMO group has IT governance and support at both the Statewide and DOT levels. At the enterprise level, the Agency for State Technology (AST) under the Department of Management Services provides State agencies with guidance and strategic direction on areas such as cybersecurity and data analytics, while also providing master contracts for essential technology services. Within FDOT, the Office of Transportation Technology (OTT) aligns IT strategies and operations to support the safety and connectivity of Florida's roadways.

Targeted efforts to clarify roles and responsibilities have improved coordination between the various groups. In general, the State AST staff focus on the IT security aspects, documentation, policy, and IT business processes while FDOT OTT staff focus more on the operational implementation of technology. Separate from both groups, FDOT TSMO staff manage the IT-TSMO systems and devices.

Within FDOT, TSMO and OTT have closely coordinated to better understand each other's skills and strengths. Specific to planning efforts, TSMO included OTT staff in the development of the TSMO Strategic Plan and continues to clarify roles and responsibilities in the CAV Plan. From an ongoing perspective, senior managers from OTT attend FDOT Statewide TSMO, ITS, and CAV workshops to remain engaged with the TSMO related IT needs and issues. FDOT staff indicated that these ongoing efforts in the planning stages have improved coordination during the implementation stages.

Chapter 3 addresses key challenges relating to domain components in terms of organization, staff, and financial resources.

**Domain Components**

The functions served by each discipline determine the structure of the key functional components of each domain, including business units and their characteristic systems and devices.

For TSMO, the domains consist of field devices and third-party data sources, central servers, and the communication components that link them, which are substantially managed out of a TMC. While TSMO has key back-office, information-based activities in a TMC, most of the assets are

in the field, presenting a significant difference compared to other functions and services supported by IT. Operating, troubleshooting, and maintaining devices in a field setting with its safety and security implications presents different challenges compared to the office environment that characterizes most IT contexts.

IT domains consist of data centers or back-office systems, database systems, and the internal and external network communications that link them. Physical devices and assets are primarily business-oriented, rather than operations-oriented, and are located in an office environment. Security of the networks and assets is essential. The TSMO and ITS functions are only a small subset of most Statewide or agency-wide IT domains, which are quite large.

One example of an emerging practice is illustrated below, in which an issue of TSMO field network needs versus Statewide network limitations was resolved.

**Domain Network Location and Support**

The Louisiana Office of Technology Services (OTS) is the centralized IT support group that provides enterprise-level network and security support. While the Louisiana Department of Transportation and Development (LADOTD) has internal IT staff that support ITS and communication needs, as well as triage issues, some TSMO functions operate on the Statewide network, and therefore are affected by activity and changes implemented by OTS.

An example of a conflict between the Statewide network and local ITS functionality involved the loss of video after OTS implemented new security policies. All computers connected to the enterprise network lost the ability to play multicast video. To resolve the issue, LADOTD moved the computers to an existing LADOTD-specific network that did not have the newer security protocols that caused the conflict. While this was considered a temporary solution, the issue highlights the importance of network maintenance in a network that supports continuous (24/7) functionality.

Chapter 3 addresses key challenges relating to domain components in terms of organization, staff, and financial resources.

**Risk Management and Security**

Although both TSMO staff and IT staff may use the same or similar tools to manage risks, their views of what constitute risks and the severity of given risks may be quite different.

For TSMO staff, the most important risks deal with external customer life-safety issues and providing a safe transportation system. Failure of transportation system elements for any reason when they are needed is essentially a system failure and pose significant risks to the traveling public. These risks are greatest when the elements are needed most, during period of high congestion or traffic disruptions and emergencies. Thus, TSMO risk management emphasizes the need for systems and devices to fail-safe or fail-soft and the need to schedule troubleshooting and maintenance with minimum impact of real-time systems operations.

Risks from the perspective of IT staff are viewed from a system integrity perspective, often on a jurisdiction-wide basis. It is important to have the entire IT network, data, and other IT assets

protected from unauthorized intrusion because this can compromise the entire enterprise network, including financial systems and private data. Thus, the IT focus within TSMO must not only accomplish the needs of the TSMO organization but also protect the enterprise network from intrusion and protect the confidentiality, integrity, and reliability of agency data.

One example of emerging practice is illustrated below, in which an issue of security of data sharing and network access was solved through structured data-sharing agreements.

**Define Data and Access Agreements to Maintain Security**

Within Maricopa County, Arizona, several local agencies share a regional fiber network and data archival system that they jointly developed as part of a Federal Highway Administration (FHWA) Metropolitan Model Deployment Initiative. The platform—managed by a regional operations coalition, called AZTech—involves participation by each independent agency, which also involves coordination across many independent IT departments and offices that that may not have been involved in the Model Deployment effort and may not fully understand the overall mission.

Sharing communication networks and agency data requires technical interoperability, or data compatibility at a minimum. Differing network structures and security protocols within the AZTech stakeholder agencies have resulted in firewall issues and restrictions in data and network access and data management and can make data and system integration more difficult. This is compounded by staff turnover and changes in leadership or equipment.

To ensure continuous functionality of the system, the AZTech partners developed data-access and data-sharing agreements that outline the requirements of participation. The agreements hold agencies accountable for maintaining an agreed upon level of access and providing a particular data stream for regional archive. The AZTech partners also identify responsibilities for maintenance, operation, and expanding the shared network. The importance of the agreement increases as time advances due to the number of changes that could purposefully or inadvertently change the agencies included in AZTech or their level of participation.

Chapter 3 addresses key challenges related to risk management and security.

**Standards and Architecture**

While both TSMO and IT have discipline-specific criteria, TSMO criteria are embedded in systems architectures that have their own demands.

TSMO has a strong, systems engineering basis with a specialized approach to the architecture needed for efficient deployment and operations of TSMO applications, combining communications, control, information, and supporting hardware and software. Federal programs have introduced requirements for ITS systems engineering[2] and a National ITS Architecture.[3]

[2] See 23 CFR Part 940.
[3] See 23 U.S.C. 517.

Voluntary or non-Federal IT standards typically revolve around a broad set of security, technology compatibility, and a variety of developed hardware and software standards that serve the full range of IT services and applications across multiple activities and agencies at the agency or Statewide levels. IT staff need to comply with State legal or State Chief Information Officer (CIO) mandated standards and policies that serve the full range of IT services provided, whether for transportation or other agencies. While there are formal, non-Federal IT certifications for network management, project management, system design and development (examples include Cisco Certified Network Professional and Cisco Certified Internetwork Expert, Microsoft Azure and Dynamics 365, Project Management Institute (PMI) Project Management Professional), most organizations do not require these certifications for an employee to work on a particular technology component.

One example of an emerging practice is illustrated below, in which the challenges of integrating disparate TSMO systems deployed over a long-time horizon is being addressed by the Tennessee Department of Transportation (TDOT).

**System Integration to Maintain Legacy Systems**

Like many public agencies, Tennessee Department of Transportation (TDOT) deployed technology systems throughout the past several decades. Due to the significant financial and human capital costs associated with the larger systems, many systems are maintained despite limited available replacement technology.

TDOT had several legacy systems that functioned and provided their intended use but did not work together and were not consistently interoperable. These systems were developed ad hoc over the years and not coordinated due to various reasons, including schedule, technology, or funding. While the lack of interoperability prohibits some efficiencies, TDOT is attempting to integrate (or develop interfaces) between the older systems and newer systems as technology becomes available and installed.

Chapter 3 addresses key challenges associated with standards related to systems and technology.

**Devices and Assets**

There are significant differences in how TSMO and IT devices and systems are managed and maintained, partially because of the differences discussed previously. TSMO assets are mission critical, and the processes for maintaining and repairing TSMO devices are specific to devices and locations that have limited physical access and downtime constraints. Because transportation field equipment generally lasts longer than most IT devices due to their hardened nature, the result is often a mix of new and legacy equipment that requires a broad range of troubleshooting and repair skills to maintain. Aside from the technology and physical location challenges, transportation systems often include multiple agencies, which involves data sharing and collaboration with multiple partner organizations.

IT systems are applied to a wide range of functions within and among agencies and across the networks and standardized equipment of entire jurisdictions. Configuration management, data governance, and data management are becoming more important features of managing IT systems,

for which IT staff need to have access to both equipment and data, which in turn introduces challenges of system and data access control and identity verification. Procurement and licensing of software and technology are often managed on a jurisdiction-wide basis with both financial and performance implications regarding the special needs and priorities on any specific agency or unit.

One example of emerging practice is illustrated below, in which a holistic lifecycle approach was introduced to support the role of IT in maintaining and replacing ITS devices and systems.

**Develop Lifecycle Costs to Support Device and Asset Maintenance and Replacement**

The money required to deploy and maintain IT-TSMO systems can be significant and requires annual resources both in terms of staffing and maintenance. Within the Pennsylvania Department of Transportation (PennDOT), various groups deployed ITS features without considering product lifecycle, technical support, or replacement costs. As a result, PennDOT developed an approach to evaluate their IT and ITS investments from a holistic lifecycle cost perspective.

The largest hurdle involved in the lifecycle approach was inventorying everything in the field and understanding what was installed, what purpose it was serving, and how it related to other features. This involved a systems approach to map out the inventory from software platform to network connections to field device.

Not only did the cost of staff resources who maintain and service the equipment increase with the number of assets installed, but each District had preferred vendors and manufacturers. Staff and budget constraints within PennDOT prevented IT from supporting the number and variety of equipment and systems. As such, to increase the efficiencies within the IT group and ultimately reduce recurring costs, PennDOT simplified the number of available manufacturers and required projects to remain within the standards.

From the reverse perspective, adding technology to automate functions can be beneficial to the lifecycle cost. PennDOT identified value in providing communication to traffic signal corridors and allowing remote connectivity. The increased investment in technology offset the ongoing time investment for managing the signals and resulted in an overall cost savings because staff could modify timing remotely.

Chapter 3 addresses the key challenges associated with managing systems in terms of systems and technology, procurement, and risk/security.

**Future Technologies**

Although many of the underlying future technologies will be the same for both TSMO systems and IT systems, there are some notable differences.

The technologies that will be incorporated into transportation systems will largely focus on efficiency improvements and utilizing expanded data sources to improve transportation control systems and decision-making. Technologies that support connected and automated vehicles, Smart Cities, mobility on demand, and other emerging concepts will be critical to meet growing

transportation needs and challenges.[4] Technologies used will often be substantially driven by the market and often initiated by the private sector.

The technologies that will be incorporated into IT systems will be driven by evolving internal business needs across an agency. Trends include a movement toward more cloud storage and cloud-computing, mobile access, and more reliance on increasingly sophisticated web services. These technologies will allow a greater independence from specific physical assets and locations. Flexibility, physical security and cybersecurity, and a reduction in capital investments will be the drivers in adopting new technologies for IT.

One example of emerging practice is illustrated below, in which a TSMO program uses outside technical support to obtain special technical capabilities.

**Outsource Services for Support**

TSMO-based operational activities and strategies are continuous (24/7/365) efforts that do not follow standard business hours. As such, LADOTD (like many other agencies) often needs IT support during unplanned IT events or failures. However, the statewide IT group, the Louisiana Office of Technology Services (OTS) is not accustomed to supporting systems in real-time.

As a large Statewide IT provider, the Louisiana OTS operates on a ticketing system and typically responds in the order that tickets are received, which could delay service to the LADOTD ITS group. This approach does not align with the urgency experienced during a technical failure within a traffic operations group. In addition, the OTS technical support staff work typical Government business hours, meaning there is no service available on weekends, holidays, and after-hours. This can present issues when the enterprise network experiences problems or email or communication systems failures.

To address the operational needs of the group, the LADOTD ITS group has outsourced services to both vendors and engineering firms. These businesses, particularly the vendors, are often more familiar with the ITS technology than OTS staff and may have helped design or install the systems. The outsourcing also provides the LADOTD increased flexibility in terms of response timeframes and the contracting allows more leverage over performance.

Chapter 3 addresses the key challenges associated with future challenges in terms of systems and technologies.

**Summarizing Differences on Perspective**

This section highlighted the differences in perspectives and program management priorities between TSMO and IT professionals. These distinctions are summarized in table 1.

[4] "A smart city is a framework, predominantly composed of Information and Communication Technologies (ICT), to develop, deploy and promote sustainable development practices to address growing urbanization challenges." Smart Cities and Integrated Mobility: A White Paper. Polytechnique Montreal, June 2018.

**Table 1. Understanding the differences between TSMO and IT staff perspectives.**

| Concept | What is helpful for IT professionals to know about the TSMO environment and processes. | What is helpful for TSMO professionals to know about IT environment and processes. |
|---|---|---|
| **Governing Principles** | Ensuring safe and efficient day-to-day operations through:<br>• Maximizing system "uptime," especially during critical demand.<br>• Operating systems whenever conditions dictate, 24/7.<br>• Interfacing with outside parties to share data, information, and control.<br>• Specialized functions merging technologies and operational strategies. | Ensuring reliable business focused delivery of services through:<br>• Maximizing IT system "uptime," especially during peak use.<br>• Operating IT systems and networks according to business needs, 24/7.<br>• Ensuring cybersecurity.<br>• Project and portfolio management requires additional levels of security and structure to manage resources. |
| **Domain Components** | Multiple domains that must work together include:<br>• Traffic operations center/data center.<br>• Data sources from third parties and field devices on roadside.<br>• Communications to link centers and data sources.<br>• Substantial domain elements are in the field.<br>• Some TSMO system elements are shared among multiple jurisdictions. | Multiple domains that must work together include:<br>• Data center/back office.<br>• Database.<br>• Security.<br>• The domain environment is primarily within a building.<br>• Internal and external network communications. |
| **Risk Management** | Considered from transportation system operations perspective:<br>• Transportation systems are operational 24/7.<br>• Business needs lead to a requirement that systems fail-safe or fail-soft.<br>• Risks are magnified during peak traffic times or during major incidents or emergencies.<br>• Troubleshooting should occur with minimal impact to system operation. | Considered from software/hardware and network resilience perspective:<br>• System outages can affect enterprise-wide business continuity.<br>• Unauthorized intrusions can jeopardize network-wide operations, including financial systems and private data.<br>• Data confidentiality, integrity, and reliability is essential.<br>• Inconsistent systems and applications can increase repair time and cost. |

**Table 1. Enhancing common understanding between TSMO and information technology staff. (continuation)**

| Concept | What is helpful for IT professionals to know about the TSMO environment and processes. | What is helpful for TSMO professionals to know about IT environment and processes. |
|---|---|---|
| **Standards and Architecture** | The range of standard practices include:<br>• Systems engineering and ITS architecture standards.[1]<br>• ITS device standards (such as the National Manual on Uniform Traffic Control Devices).<br>• Hardened equipment (maximum availability).<br>• Technicians often need specialized certification for field work. | The range of standard practices include:<br>• State legislated/CIO mandated standards and policies.<br>• Enterprise architecture.<br>• Technology compatibility standards.<br>• Non-Federal hardware and software standards.<br>• Non-Federal security standards. |
| **Devices and Assets** | Managing TSMO assets emphasizes:<br>• Needs for maintaining and repairing traffic management devices are specific to device and location.<br>• Generally, equipment replacement is on a longer cycle than IT equipment (sometimes because the cost of TSMO equipment is higher than for IT equipment), resulting in old legacy systems in use with limited capabilities but high reliability.<br>• TSMO equipment includes analog, digital, and mixed environments requiring a mix of skills to troubleshoot and maintain the breadth of technologies.<br>• TSMO equipment rarely receives dedicated funding in DOT budgets and often must compete with road and bridge construction for funding. | Managing IT assets emphasizes:<br>• Maintaining software and hardware components to manufacturer supported levels.<br>• Relatively shorter lifecycle than TSMO assets.<br>• Technology asset and license management.<br>• Performance and uptime/availability.<br>• Data governance and data management.<br>• Network engineering and management.<br>• Configuration management protocols.<br>• State and other non-Federal agency procurement policies, rules and processes governing technology purchases. |
| **Future Technologies** | Technology considerations include:<br>• Using emerging technologies and sources of data (automated vehicles, connected vehicles, Smart Cities, etc.) is critical to meet growing transportation needs and challenges effectively and efficiently.<br>• Many of the new technologies are market related and come out of the private sector. | Technology considerations include:<br>• Managing ever evolving advances in hardware/software with business needs.<br>• Movement toward more cloud-computing and web services. |

[1] See 23 CFR Part 940.

[2] See 23 CFR 655.603(a).

(Source: FHWA.)

By examining the table, one can highlight some potential important differences in perspective between IT staff and TSMO staff. These differences demonstrate varying understanding of terminology, practices, policies, focus areas, and viewpoints.

# CHAPTER 3. CHALLENGES OF INFORMATION TECHNOLOGY AND TSMO COORDINATION AND RELATED PRACTICES

The relationships between TSMO staff and IT staff have evolved significantly. As noted in chapter 2, the differences between the disciplines suggested the importance of learning experience regarding improved understanding and cooperation.

This project, through literature review interviews and project team experience, has:

- Analyzed and described the key IT-related challenges facing TSMO staff.
- Identified examples of practices responding to these challenges that States have found valuable in overcoming IT-related challenges and in improving the relationship between TSMO staff and IT staff.

This chapter presents both a challenge-driven view of the payoff for practices (including a correlation matrix) as well as a practice-driven view (including their crosscutting applicability).

## CHALLENGE-PRACTICE RELATIONSHIPS

There has been a wide range of "lessons learned" to deal with the identified challenges, category by category. By and large, this experience has not been substantially documented, and thus this project primarily drew from the experience of practitioners through interviews, listening sessions, and webinars.

For the eight categories of challenges, there are practices that are beneficial for coordination across a range of cases and contexts. Where available, specific agency examples are provided. It is important to recognize that, in many cases, the lessons learned examples are a point of departure for continuing evolution for individual agencies over time in developing responses to the challenges. Through this review the project team found that (1) a given challenge could be supported by multiple practices, and (2) some practices could help address multiple challenges.

A key finding of this project, as reflected in the challenge matrix, is that there is not a one-to-one relationship between a challenge and a specific practice related to that challenge. That is, multiple practices, or combination of practices, could address any given challenge. For example, in table 2, related to culture, the challenge related to scarce resources may require multiple approaches, reflected in the four distinct practices that are presented. Conversely, practices can relate to more than one challenge.

Thus, examining the relationship between challenges and practices may be approached from either perspective, looking at addressing challenges by combing practices, or looking at how certain practices are applicable across a range of challenges.

For this reason, the project presents both challenge-driven and practice-driven perspectives. The challenge-driven perspective in terms of the challenge matrix is presented in the following section, which is followed by a section that summarizes the practice driven view.

The following challenge tables present a selection of situations and agency-specific potential practices associated with key challenges. The practices can be grouped into five broadly defined categories. In each group, broadly applicable general practices are identified (in italics below) together with related specific practices.

**Collaboration**

- *General Practice: Improve Communication.*
- *General Practice: Clarify Roles and Responsibilities.*

Specific practices:

- Integrate IT staff within TSMO unit.
- Modify organizational structure.
- Implement coordination policies.
- Develop formal agreements.

**Staff Capabilities**

- *General Practice: Establish Staffing Needs.*
- *General Practice: Provide Staff Training.*

Specific practices:

- Integrate TSMO staff and IT staff.
- Outsource services.
- Identify recruiting opportunities.

**Planning/Programming**

- *General Practice: Involve IT Personnel in Project Delivery Teams.*
- *General Practice: Develop Lifecycle Cost Model.*

Specific practices:

- Coordinate TSMO and IT Strategic Plans.
- Develop long-range IT-TSMO framework.
- Develop IT policies that support TSMO.

**Program Delivery**

- *General Practice: Involve IT Personnel in Project Delivery Teams*
- *General Practice: Develop Lifecycle Cost Model.*

Specific practices:

- Incorporate IT staff in systems engineering process.
- Establish TSMO "approved product list."
- Adjust procurement process for TSMO.
- Establish IT-TSMO project review.

**Equipment/Systems**

- *General Practice: Maintain an ITS Architecture.*
- *General Practice: Improve Data Communications Infrastructure.*

Specific practices:

- Develop an integrated security system with IT.
- Establish necessary decision support systems.
- Define and coordinate data sharing and access agreements.
- Create a data governance and management plan.

A more complete description of the practices is included after the challenge tables and more detail is presented in appendix B.

## THE CHALLENGE MATRIX—A TOOL TO CAPITALIZE ON EXISTING EXPERIENCE

The project team developed a "Challenge Matrix" as a tool that readers can use to identify potentially valuable and approaches to respond to the wide range of challenges experienced to date that have been identified by this project. The tables are intended to allow document users to search for the challenges they are facing by category.

The challenges are presented in eight separate tables, grouped into institutional challenge categories, and business and technical challenge categories, of four each. For each specific challenge shown, the table lists one or more potential practices that can address the challenge with a short description and a section number reference.

## CHALLENGES

Challenges discovered during this project fall into two basic categories. The first category consists of institutional challenges that can hamper programmatic activities. The second category

includes challenges in key business and technical processes that are critical to integrating TSMO and IT during TSMO program development, implementation, and operations.

**Institutional Challenges**

As characterized in chapter 2, institutional challenges reflect characteristics of the basic disciplines of TSMO and IT as they are reflected in their organizational orientation and configuration. Institutional challenges fall into four categories:

- **Cultural:** Challenges that relate to professional culture, values, and behaviors that influence personal relationships or interactions between the differing agency functions or groups.
- **Staff and Financial Resources:** Challenges addressing staffing and financial resources that are essential to fulfilling TSMO related IT needs and are required for nearly all aspects of acquisition, development, and maintenance of IT systems.
- **Organizational:** Challenges related to organizational structure, the formal and informal structural arrangements around which staffing, roles, and responsibilities are managed and carried out.
- **Policy:** Challenges that include legislation, executive-level directives, departmental policy, or requirements that affect IT or TSMO.

**Business and Technical Processes Challenges**

Business and technical processes challenges reflect the intersection between institutional challenges in the business process and technical processes integral to the pursuit of their respective TSMO and IT program objectives. Process challenges fall into four categories:

- **Planning and Programming:** Challenges related to the vision, mission, and objectives of the different organizations/functions and integrating each in the overall agency planning, programming, and resource allocation**.**
- **Procurement:** Challenges related to the processes and procedures associated with obtaining IT-intensive products or services.
- **Systems and Technology:** Challenges related to hardware and software components of data acquisition, management, and utilization technologies.
- **Risk and Security:** Challenges associated with network security, data sharing, third-party application, hosted or cloud platforms, and automation.

A full listing and more detailed description of the challenges can be found in appendix A, and a full and more detailed listing of the practices are found in appendix B. The matrices provide the indexing for this detail. The abbreviated "IDs" for each challenge provide the indexing for the challenges detailed in appendix A and the section numbers for each practice are cross-referenced to appendix B. For example, the challenge related to "Different Staff Backgrounds and Roles Leads to Silos" is described in appendix A, Culture-3. Similarly, the practice "Implement Coordination Policies" is detailed in appendix B under section B.1.2 within the "Collaboration" practices.

(In electronic versions of this document that support internal document links, the challenge ID and the practice section number are electronically linked directly to the sections in the appendices that describe challenge or practice in more detail. For the example above, clicking or selecting Ctrl+Click on the ID "Culture-3" will link directly to the description for "Different Staff Backgrounds and Roles Leads to Silos" in appendix A. Similarly, clicking or selecting Ctrl+Click on the section # "B.1.2" will link directly to the description for "Implement Coordination Policies" in appendix B.)

## Institutional Challenges

The interaction between TSMO staff and IT staff is often influenced by the organization itself, including professional culture, organizational structure, staff capabilities, and resource allocation. Challenges can arise when the organization's history, the underlying culture of its staff, or the available resources do not align with the current mission or task. Common institutional challenges can be encountered at all levels of the organization from leadership decision-making to frontline implementation.

### *Cultural*

Culture consists of the values and behaviors that influence personal relationships or interactions between the differing agency functions or groups. Culture includes technical understanding, leadership, outreach, and program legal authority. Table 2 presents the culture challenge and practice relationships. As can be seen, various mixes of six practices can address the four principal challenges.

General practices beneficial to cultural challenges:

- Improve Communication.
- Clarify Roles and Responsibilities.
- Establish Staffing Needs.

**Table 2. Cultural challenge practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| Lack of mutual understanding between TSMO staff and IT staff. | Culture-1 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| Lack of IT staff availability when TSMO staff need IT support. | Culture-2 | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop memorandum of understanding or intergovernmental agreement. | B.1.2 |
| | | Mix TSMO staff and IT staff. | B.2.2 |
| | | Outsource services. | B.2.2 |
| Different staff backgrounds and roles leads to silos. | Culture-3 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |

**Table 2. Cultural challenge practices (continuation).**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| Shared resources and references for TSMO related IT needs are scarce. | Culture-4 | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop formal agreement. | B.1.2 |
| | | Mix TSMO staff and IT staff. | B.2.2 |

(Source: FHWA.)

### *Staff and Financial Resources*

Staffing and financial resources are essential components to fulfilling TSMO and IT needs and are required for nearly all aspects of acquisition, development, and maintenance of IT systems. Table 3 presents the staff and financial resource challenge and practice relationships. As can be seen, various mixes of five practices can address the four principal challenges.

General practices beneficial to staff and financial resources challenges:

- Clarify Roles and Responsibilities.
- Establish Staffing Needs.
- Provide Staff Training.
- Allocate Budgets and Resources Based on Historical Data.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Develop Lifecycle Cost Model.

**Table 3. Staff and financial resources practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| Funding sources for TSMO related IT projects are not well established. | Resource-1 | Coordinate TSMO and IT Strategic Plans. | B.3.2 |
| | | Develop long-range IT-TSMO framework. | B.3.2 |
| Recruiting and retaining IT staff is difficult with competition from private sector. | Resource-2 | Outsource services. | B.2.2 |
| | | Identify recruiting opportunities. | B.2.2 |
| Training requirements and programs for TSMO and IT are not provided internally. | Resource-3 | Integrate IT staff within TSMO unit. | B.1.2 |
| Use of private firms to provide services requires funding, oversight, and agency approval. | Resource-4 | Outsource services. | B.2.2 |

(Source: FHWA.)

### *Organizational Structure*

Organizational structure includes the formal and informal structural arrangements around which staffing, roles, and responsibilities are managed and carried out. Table 4 presents the organizational structure challenge and practice relationships. Various mixes of eight practices can address the five principal challenges.

General practices beneficial to organizational structure challenges:

- Clarify Roles and Responsibilities.
- Establish Staffing Needs.
- Allocate Budgets and Resources Based on Historical Data.

**Table 4. Organizational structure practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| TSMO is limited in its direct interaction with IT leadership given the hierarchical structure. | Org-1 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| Lack of clarity in defining the roles of department of transportation IT staff versus enterprise IT staff and associated IT ownership. | Org-2 | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| Organizational IT capability varies across the State and may be weaker in rural areas. | Org-3 | Integrate IT staff within TSMO. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop formal agreement. | B.1.2 |
| | | Mix TSMO and IT staffs. | B.2.2 |
| | | Outsource services. | B.2.2 |
| Approval processes are challenging for the unique environment and function of TSMO. | Org-4 | Implement coordination policies. | B.1.2 |
| | | Form TSMO “approved product list.” | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| Meeting expectations and needs can be challenging when operating key business (IT) resources is the responsibility of a separate organizational unit. | Org-5 | Integrate IT staff within TSMO. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop formal agreement. | B.1.2 |
| | | Mix TSMO and IT staffs. | B.2.2 |

(Source: FHWA.)

**Outsource Services for Support**

TSMO-based operational activities and strategies are continuous (24 hours per day/7 days a week/365 days per year) efforts that do not follow normal business hours. As such, department of transportation (DOT) TSMO units often need IT support during unplanned IT events or failures. However, the enterprise IT groups are often not accustomed to supporting systems in real time.

Many State enterprise IT units operate on a ticketing system and typically respond in the order that could delay service to the DOT TSMO group. This approach does not align with the urgency experienced during a technical failure with ITS. In addition, the IT technical support staff work "normal" business hours. Limited service is available on weekends, holidays, and after hours, which can present issues when the network or other IT systems fail.

One successful approach to this problem is to work with the IT organization to determine a way for the TSMO organization to pay for IT staff to be on-call for those extended hours. If that is not a possibility or it would create policy issues with the IT organization, TSMO and IT groups working together to outsource those services for night and weekend service may be an option.

### *Policy*

Policy includes executive-level directives, departmental policy, or requirements (including any applicable legal or regulatory requirements) that are not directly targeted to TSMO or are outside the departments or divisions of either IT or TSMO. Table 5 presents the policy challenge and practice relationships. Various mixes of three practices can address the two principal challenges.

**Table 5. Policy practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| TSMO design, procurement or operations need to comply with jurisdiction-specific laws and regulations that may not have been established with TSMO in mind. | Policy-1 | Implement coordination policies. | B.1.2 |
| | | Develop formal agreement. | B.1.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| TSMO procurement processes can be affected by jurisdiction-level IT procurement rules. | Policy-2 | Develop IT policies that support TSMO. | B.3.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |

(Source: FHWA.)

### Business and Technical Challenges

Implementing technology within an agency can be affected by the business and technical processes associated with developing systems, including planning, procurement, security and data, and new technology specific challenges. Challenges can arise when processes that worked well before the

proliferation of IT systems and devices are simply no longer effective. In other situations, processes may have been developed in isolation within either the TSMO or IT organizations and worked well if the organizations remained isolated. Common business and technical challenges can be encountered at any stage of project activity or development.

### *Planning and Programming*

Strategic planning includes the vision, mission, and objectives of the different organizations or functions, and integrating each in overall agency planning and resource allocation. Table 6 presents the strategic planning challenge and practice relationships. As can be seen, various mixes of five practices can address the three principal challenges.

General practices beneficial to strategic planning challenges include:

- Allocate Budgets and Resources Based on Historical Data.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Involve IT Personnel in Project Delivery Teams.

**Table 6. Strategic planning practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| Strategic planning and governing mission, vision, and goals can differ between TSMO and IT. | Planning-1 | Coordinate TSMO and IT Strategic Plans. | B.3.2 |
| | | Develop long-range IT-TSMO framework. | B.3.2 |
| Programming and development of TSMO IT projects does not align with traditional construction or IT. | Planning-2 | Develop IT policies that support TSMO. | B.3.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| Business metrics and performance measures for TSMO are not integrated in IT unit's management. | Planning-3 | Develop IT policies that support TSMO. | B.3.2 |

(Source: FHWA.)

### *Procurement*

Procurement consists of the processes and procedures associated with obtaining IT-intensive products or services. Table 7 presents the procurement challenge and practice relationships. Various mixes of eight practices can address the five principal challenges.

General practices beneficial to procurement challenges:

- Improve Communication.

- Clarify Roles and Responsibilities.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Develop Lifecycle Cost Model.

**Table 7. Procurement practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| Statewide procurement policies and procedures do not align with TSMO initiatives. | Procure-1 | Form TSMO "approved product list." | B.4.2 |
| | | Adjust procurement process for TSMO consistent with State and local requirements. | B.4.2 |
| Purchasing activities require multiple levels of approval across groups. | Procure-2 | Develop formal agreement. | B.4.2 |
| | | Develop IT policies that support TSMO. | B.4.2 |
| | | Form TSMO "approved product list." | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| Business needs for TSMO require both legacy and emerging systems. | Procure-3 | Develop long-range IT-TSMO framework. | B.4.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| Lack of pre-approved TSMO related IT equipment/services can slow efforts. | Procure-4 | Form TSMO "approved product list." | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |

(Source: FHWA.)

### *Systems and Technology*

Systems and technology encompass all hardware and software components of data acquisition, management, and utilization technologies. Table 8 presents the systems and technology challenge and practice relationships. As can be seen, various mixes of 10 practices can address the seven principal challenges.

General practices beneficial to systems and technology challenges:

- Improve Communication.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Involve IT Personnel in Project Delivery Teams.
- Maintain an ITS Architecture.
- Improve Data Communications Infrastructure.

**Table 8. Systems and technology practices.**

| Challenge Description | ID | Effective Description | Section # |
|---|---|---|---|
| Challenges maintaining legacy systems and deploying emerging technology. | Tech-1 | Develop long-range IT-TSMO framework. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| | | Establish necessary decision support systems. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| Insufficient communication system bandwidth and redundancy for TSMO services. | Tech-2 | Develop long-range IT-TSMO framework. | B.3.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| | | Create a data governance and management plan. | B.5.2 |
| Complications with interoperability between agencies and partners. | Tech- | Develop formal agreement. | B.1.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| Inability to fully utilize third-party data and crowdsourcing data and services. | Tech- | Develop long-range IT-TSMO framework. | B.3.2 |
| | | Develop IT policies that support TSMO. | B.3.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| Emerging technology in connected and autonomous vehicle (CAV) and Smart Cities requires significant IT resources. | Tech-5 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Develop IT policies that support TSMO. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| | | Create a data governance and management plan. | B.5.2 |
| TSMO initiatives are impeded due to lack of IT flexibility in enterprise operations. | Tech-6 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Develop IT policies that support TSMO. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| Designing complex ITS requires a systems engineering approach with which IT staff may not be familiar. | Tech-7 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |

(Source: FHWA.)

### *Risk and Security*

Risk and security include those challenges associated with network security, data sharing, third-party applications, hosted or cloud platforms, and automation. Table 9 presents the risk and security challenge and practice relationships. As can be seen, various mixes of 12 practices can address the six principal risk and security challenges.

General practices beneficial to risk and security challenges:

- Improve Communication.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Involve IT Personnel in Project Delivery Teams.
- Improve Data Communications Infrastructure.

**Table 9. Risk and security practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| Cybersecurity vulnerabilities. | Risk-1 | Integrate IT staff within the TSMO. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Outsource services. | B.2.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| Lack of robust data governance rules. | Risk-2 | Develop formal agreement. | B.1.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| Increased sharing of information with third party can increase security risks. | Risk-3 | Develop formal agreement. | B.1.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| Location of TSMO network has impacts to security, support, and availability. | Risk-4 | Develop IT policies that support TSMO. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |

**Table 9. Risk and security practices. (continuation)**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| Automated data sets and analyses can mask reliability issues. | Risk-5 | Mix TSMO staff and IT staff. | B.2.2 |
| | | Establish necessary decision support systems. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| Field equipment is susceptible to physical damages. | Risk 6 | Form TSMO "approved product list." | B.4.2 |

(Source: FHWA.)

## PRACTICES

This section synthesizes the "lessons learned" through the project research and provides a range of current practices to deal with the common challenges described in the section above. The individual practices are categorized within functional groups based on common approaches.

It is important to understand, as discussed above, that combining practices may be helpful when dealing with specific challenges. That is, there is no one-to-one relationship from practices to challenges or from challenges to practices. Users of this document may wish to consider their context-specific issues from either direction.

In the discussion below, practices are grouped into five broadly defined categories:

- Collaboration.
- Staff capabilities.
- Planning/programming.
- Program delivery.
- Equipment/systems.

Within each category, there are one or two general high-level approaches or practices that are beneficial for coordination as well as a set of specific practices that address specific challenges.

Specific agency examples are provided for individual practices based on interviews and outreach efforts.

### Collaboration Practices

There are many challenges in coordinating and integrating TSMO and IT considerations that are encountered because of differences in culture, differential availability and applicability of resource needs, standard organizational structures and expectations, and technology considerations such as applicability and flexibility needs.

Each of these challenges requires new forms or levels of collaboration between TSMO and IT units, and their respective professionals. Such collaboration may be informal or formal. Examples of informal collaboration include increasing the understanding of IT and TSMO objectives, clarifying roles, and integrating staff. More formal efforts relate to modifying organization structures, implementing policies, and creating intergovernmental agreements (IGAs) or memorandums of agreement (MOUs).

### *Collaboration General Practices*

#### *Improved Communication*

The general practices supporting and reflecting improved collaboration depend heavily on improved communication among respective staffs, typically in the form of regular meetings or facilitated workshops. Initial meetings could take the form of a facilitated workshop or partnering session to develop a common understanding of each group's business goals, needs, and priorities. The meetings could evolve into forming an IT advisory group that could identify and recommend solutions to a wide variety of issues that can produce benefits from both TSMO and IT perspectives.

**Regularly Scheduled Meetings to Improve Communication**

To promote mutual understanding and improve working relationships, the Louisiana DOT and Development and the Louisiana Office of Technology Services (OTS) meet on a regular basis to discuss IT needs for maintaining ITS operations. These meetings are attended by a "client manager" within the enterprise OTS that is assigned to the Department of Transportation and Development (DOTD). These meetings have increased OTS' understanding of ITS systems and improved its ability to provide support. Similarly, the DOTD ITS staff now have a better knowledge of the enterprise OTS organization and how to obtain technical support.

#### *Clarify Roles and Responsibilities*

An important crosscutting activity, and a key product of improved communication, is to clarify the respective roles and responsibilities of TSMO versus IT units and staffs. Available organization charts and directive responsibilities can be helpful in this regard This is particularly important because it relates to shared facilities or functions, as can be the case between TSMO and IT, which can play an important role in reducing confusion in obtaining service, justifications, and approvals. Managing devices and assets is an example of the importance of identifying and clarifying roles and responsibilities. IT staff members have knowledge and experience in maintaining important IT-related assets and systems, IT-related service contracts, network devices and network management systems, software, and data analytics tools. Assigning IT staff to these assets and systems can prove to be effective and efficient.

**Clarify Roles and Responsibilities**

Like many public agencies, Florida DOT's TSMO group has IT governance and support at both the enterprise level and the DOT level. Their enterprise level provides the State with guidance and strategic direction on areas such as cybersecurity and data analytics, while also providing master contracts for essential technology services. Within the DOT, the internal IT staff are responsible for aligning IT strategies and operations to support the safety and connectivity of the roadways.

Coordination between the various groups has been improved through targeted efforts to clarify roles and responsibilities. In general, the enterprise IT staff focuses on the IT security aspects, documentation, policy, and IT business processes while DOT IT staff focuses on the operational implementation of technology. Separate from both groups, the TSMO staff manages the ITS/TSMO related IT systems and devices.

Within the DOT, TSMO and DOT IT have closely coordinated to better understand the skills and strengths of each other. Specific to planning efforts, TSMO included IT staff in developing the TSMO Strategic Plan and continue to clarify roles and responsibilities in the Connected and Automated Vehicle (CAV) Plan. From an ongoing perspective, senior managers from the IT group attend statewide TSMO, ITS, and CAV workshops to remain engaged with the TSMO related IT needs and issues. These ongoing efforts in the planning stages have improved coordination during the implementation stages.

*Collaboration—Specific Practices*

This project identified four specific practices with broad applicability across several challenges, as indicated in the challenge-driven section above:

- **Integrate IT staff within TSMO unit—**Creating opportunities for IT staff to work within the TSMO structure on current activities can enhance collaboration and improve their understanding of the TSMO mission as well as the end-user experience of data and software platforms.

  These opportunities can range from permanent assignments to temporary rotations to routine (e.g., weekly or monthly) visits or assignments for specific projects. The assignments may include onsite IT support tasks or observing TSMO operations.

**Integrate IT Staff Within TSMO Workgroups**

The Pennsylvania Turnpike Commission (PTC) relies on its TSMO and IT staffs to maintain system functionality and provide continuous customer service. As is typically the case, the IT and TSMO staffs came from different backgrounds, which led to perceived or actual silos. Historically, this then led to "shadow IT" use by the TSMO staff (i.e., the use of technology without the knowledge or approval of the formal IT department).

To overcome these silos, the PTC integrated IT staff into its operations business so that there was better understanding and collaboration. An IT Advisory Board was established to provide overall technology direction and initiatives rather than just providing approvals on individual projects. The IT staff was also included in major efforts such as the TSMO Capability Maturity Model (CMM) workshop.

The PTC now sends IT staff into the field three to four times a year to work with and observe operational field staff. This interaction provides IT staff with a better perspective of day-to-day operational needs and how IT can positively impact TSMO operations. This has also helped IT staff evolve from being strictly technology experts to understanding how IT relates to project management needs.

- **Modify organizational structure—**Agencies can use organizational changes to formalize relationships within transportation agencies between TSMO and IT groups. The changes can range in degree from creating individual positions to creating small units to address coordination and collaboration between TSMO and IT. Organization charts can be used to reflect reporting relationships within transportation agencies where IT resources are part of the agency, indicating specialized oversight or coordination responsibilities. Organization charts may also illustrate relational links that clarify roles and assignments while keeping IT staff within the IT structure. In some cases, assignment of IT-TSMO liaison personnel can provide a valuable function.
- **Implement coordination policies**—To increase interaction between the TSMO and IT groups, agencies can develop internal policies and procedures that require mandatory "touch points" for coordination through either existing or new processes. These efforts can relate to planning, scoping, project delivery, performance measures, security assessment and mitigation, or other steps that may involve both groups or would benefit from the input of both groups.
- **Develop Formal Agreement—**Formal written agreements can serve an important function in clarifying to all involved parties the respective roles and responsibilities of the agencies party to the agreement. Formal agreements have the virtue of surviving changes in leadership or staffing. An MOU or an intergovernmental agreement (IGA) can serve as a formal contract documenting these roles and responsibilities.

  Even across internal agency divisions or offices, agreements may be important to have in writing. Such agreements may take the form of relatively informal memos or even emails or may be formalized in service-level agreements.

**Increased IT-TSMO Coordination**

Most Statewide IT departments or offices provide oversight of all IT efforts across the various State agencies, which often leads to approval processes that are very rule-driven and time consuming. In California, Caltrans found the approval process timeframes were creating delays in budget approvals and project delivery because of a lack of delegation outside the Department of Technology.

To combat the challenges, Caltrans identified a dedicated liaison to work directly with the Department of Technology staff to provide project justifications and gain internal approvals. The liaison was a senior staff member who had deep knowledge of the individual technology (hardware, software, data) and the how these pieces contribute to the agency's goals and operational procedures. The IT liaison met weekly with the enterprise IT staff to discuss general issues and monthly to work on specific projects.

The coordination effort with the Department of Technology was beneficial and resulted in increased value to Caltrans. By involving IT staff early in the process, the Department of Technology could help develop the vision for the project, assist in procurement strategies, and assess the future IT maintenance and support needs. Similarly, the IT staff view the additional touchpoints positively and there has been increased interest in transportation, particularly with standardizing software, equipment, security, and big data.

## Staff Capability Practices

A range of practices relate to staffing to access the necessary capabilities to support the IT function within TSMO programs. Staffing challenges range from defining the core technical capabilities required but also the availability of key resources on a 24/7 basis. Given scarce resources both within TSMO and IT functions at the State and unit levels, acquiring the needed capabilities may rely on several practices.

### *Staff Capabilities General Principles*

*Establish Staffing Needs*

To facilitate IT coordination, any technology-based TSMO effort can detail the IT resources required to develop, operate, and maintain TSMO related IT functions or systems. This effort can be based on historical efforts (if available) or projected needs and can include required staff skillsets in addition to number of staff members. In response, IT organizational units can develop a staffing plan to ensure resources are available or a plan to obtain the skillsets both in the short-term and the long-term. A key consideration is defining the core capabilities that are required in-house on a recurring basis—versus specialized expertise that may be accessed through outsourcing.

*Provide Staff Training*

Appropriately combining knowledge, skills, and abilities (KSA) is essential for TSMO. Agencies may wish to access training opportunities for TSMO and IT staffs to build adequate internal

resources and maintain consistency in the agency. Training not only increases staff and agency technical capability but can also provide promotional opportunities and indirectly increase retention through personal growth. Continuing training is also essential—at several levels—to maintain competence considering evolving technology and issues. Cross-training may be important to improve staff flexibility. There is a broad range of training modes—internal and external.

**Staff Training Opportunities**

The National Operations Center of Excellence provides a searchable TSMO training database (https://transportationops.org/training) that includes several IT-related topics, such as:

- Data management and governance.
- ITS procurement.
- System security.
- Telecommunications and networking.

On the same website, there is a section on student education that includes listings of undergraduate and graduate courses.

### *Staff Capabilities—Specific Practices*

This project identifies three specific practices that can address challenges that relate to maintaining organizational culture, organizational structure, resource requirements and risk management:

- **Integrate TSMO staff and IT staff—**The staffing of TSMO and IT, even where separate organizationally, can be integrated to deliver the required agency resources to maximize staff availability, staff knowledge, and coordination. Given fluctuating workloads, borrowing resources between the groups can help augment staffing and provide continued delivery and continuous availability of services. In critical situations such as equipment failures or after-hours efforts, this can result in quicker response times and less downtime.

**Mix TSMO and IT Staffs**

Within Maricopa County, AZ, a regional fiber network and data archival system was developed to support multiple public agencies across an entire metropolitan area and to integrate the various ITS systems. The coordination was led by a coalition formed in 1996, AZTech, which cooperates on regional ITS projects and consists of representatives from the various agencies.

To support the coalition, Maricopa County loaned an IT person to directly support the development of center-to-center communication and the fiber network. By assigning an IT person to the TSMO/ITS effort, the coalition could direct priorities and timeframes without outside influence from agency IT groups. After the initial fiber network was complete, the dedicated IT person remained embedded in the TSMO/ITS group, because they understood the operations and functions better than available enterprise IT groups. As efforts continued to build an archiving platform, data support became a critical function that was supported by a different dedicated role that specialized in TSMO data rather than relying on an IT generalist from an enterprise group.

Through shared resources between the partner agencies, dedicated IT and data staff remain who support the regional mission. Each staff member is available to the partner agencies to support the needs of the TSMO/ITS operational staff.

- **Outsource services—**Outsourcing services, such as IT staffing, can provide agencies with the flexibility to properly staff for typical workloads while still obtaining resources when needed for specific skills, projects, or periods. Outsourced, external services can be provided in several ways, including defined project assignment or delivery, supplemental in-house staff, or as-needed on-call staffing. Outsourced services can be provided in different locations, onsite or remote. Outsourcing can be particularly attractive and effective for specialized skills, such as communication network management and cybersecurity assessment and mitigation. The procuring and contract managing of outsource service itself require special management skills and require advance planning.

**Outsource Services—To IT Department**

After the State of Michigan centralized all IT services in the Department of Technology, Management and Budget (DTMB), Michigan DOT's TSMO Planning activities identified frustrations with working on IT issues. Michigan DOT ITS Program Office staff identified ways to work more effectively with DTMB. They included DTMB staff in all conversations from concept to implementation. ITS Program Office staff found they needed to better understand the "rules of engagement" on IT-related projects and that keeping DTMB staff involved to identify IT needs helped understanding on both sides. The ITS Program Office used their funds to have DTMB staff assigned to the ITS Program Office. Some areas of note where DTMB staff have been very helpful include:

- Network addressing.
- Allocating cybersecurity specialists.
- Helping translate between IT and Operations staffs.

Before including DTMB staff from the very beginning of a project, Michigan DOT used to get far down the project/procurement path and fight to keep Michigan DOT the lead for software and technology procurement. Now they have a cooperative, hand-in-hand approach to use IT procurement processes and allow IT to manage the procurement. Michigan DOT consultants develop business requirements, and Michigan DOT uses the IT procurement process.

An example of this cooperation is in communication network development. Previously, Michigan DOT would design communication networks for a specific purpose with specific ITS equipment and specific network equipment. Then, adding other network equipment was often a problem because the original rules needed to be changed. The resulting problems could affect physical network or device addressing (assigning IP addresses) or the need for virtual private networks. Michigan DOT found that, in some circumstances, they needed to reconfigure the network. They are now thinking about working with DTMB staff to develop an overall network strategic plan to better configure the network for future needs.

Michigan DOT is leveraging the relationships between DTMB and the ITS Program Office for other types of systems, like signal systems. which are not included in the ITS Program Office.

- **Identify recruiting opportunities—**Recruitment for TSMO- and IT-related positions in the current environment requires agencies to develop new approaches that widen the potential candidate pool. While some positions are filled by internal transfer, acquiring experienced staff require communication with potential hires from a wider variety of sources beyond recent graduates and other agencies. In addition, given private-sector competition, it may be important to emphasize the unique challenges and opportunities available in scope and scale of IT-TSMO efforts that may not be available in the private sector as well as identifying the conditions and employment career benefits (such as stability, defined career paths, technical exposure, pensions, and insurance) or public service (such as improving safety or congestion).

**Improving Staff Recruitment and Development**

DOTs can have trouble recruiting for positions that require multidisciplinary knowledge required in TSMO due to private industry competition and internal human resources constraints.

To combat this issue, in addition to hiring staff through their traditional human resources processes, Florida DOT augments general criteria with some potential TSMO roles and responsibilities within the job description. Once hired, staff is cross trained on the job with experienced in-house staff to develop the necessary knowledge, skills, and abilities to carry out the required job functions. Due to the increased need to train staff, Florida DOT has documented many of the IT processes so that there is standardized understanding of the systems, processes, and institutional knowledge is not lost.

While the above approach has worked in obtaining staff, it can be difficult to retain staff. Once trained, some staff have taken their increased skill levels and left for higher-paying opportunities after a few years. The State's use of consultants for supplemental services has allowed some pay rates to increase to help provide more stability, but the agency still sees the most experienced persons leaving and/or retiring.

**National Operations Center of Excellence Resources**

The National Operations Center of Excellence provides valuable resources in workforce development. A page on their website (https://transportationops.org/workforce/hrresources) provides guidance for recruiting TSMO positions. The guidance applies to a wide variety of positions, including those related to IT. The topics include:

- Developing a recruitment plan.
- Determining when to recruit.
- Determining where to recruit.
- Considering the use of a recruitment specialist.
- Developing the screening and interview process.
- Determining incentives.

**Planning/Programming Practices**

A range of practices relate to planning and programming of TSMO that require IT to support early plan coordination, develop long-range needs, and allocate and maintain adequate budgets.

Planning and programming challenges range from establishing the business case for TSMO in support of defining financial and staff needs, identifying the resources required for maintaining legacy systems and accessing new technology and data sources, and recognizing key IT specific policy and program issues.

### *Planning and Programming General Principles*

*Allocate Budgets and Resources Based on Historical Data*

To ensure IT-TSMO budget and resource needs are sufficiently and accurately described, budget requests are most compelling when based on historical cost data as applied to anticipated future needs. Separating costs by function or area can be useful in applying for different funding sources, such as TSMO versus IT, and can assist in managing the budgets during the fiscal year.

*Establish and Maintain Systems to Manage TSMO and IT Devices and Assets*

A system that tracks TSMO and related IT devices and systems can assist an agency with planning and programming by evaluating the performance of existing equipment. Asset performance information can become more accurate and reliable as data is accumulated over equipment lifecycles to support development of annual maintenance and replacement costs, staffing needs, and general planning efforts. IT staff is often knowledgeable in incorporating IT devices and systems in management systems and in managing those assets.

### *Planning and Programming—Specific Practices*

This project identifies three specific practices with broad applicability across several challenges as indicated in the challenge-driven section above:

- **Coordinate TSMO and IT Strategic Plans—**Agencies can improve integration between TSMO and IT groups by coordinating their respective TSMO and IT Strategic Plans. It may be important to create nested plans, including strategic plans, program plans, and project-level plans. Though often separate, these plans can include overlapping functions and efforts to ensure appropriate planning and programming and to help identify common priorities and resources.

  The Pennsylvania Turnpike developed a technology planning approach that integrates IT and TSMO perspectives and staffs (see figure 2). There are three primary parts of this approach.

  - **IT Needs Identification** is the process to define needs and to prioritize projects. IT and TSMO groups are involved in setting priorities.
  - **Business Plan and Project Prioritization, Monitoring, and Reporting** is focused on delivering projects according to standards on schedule and on budget.
  - **IT Needs Realization** makes sure successful projects are delivered. This includes testing, but also taking correct action from security and change management perspectives.

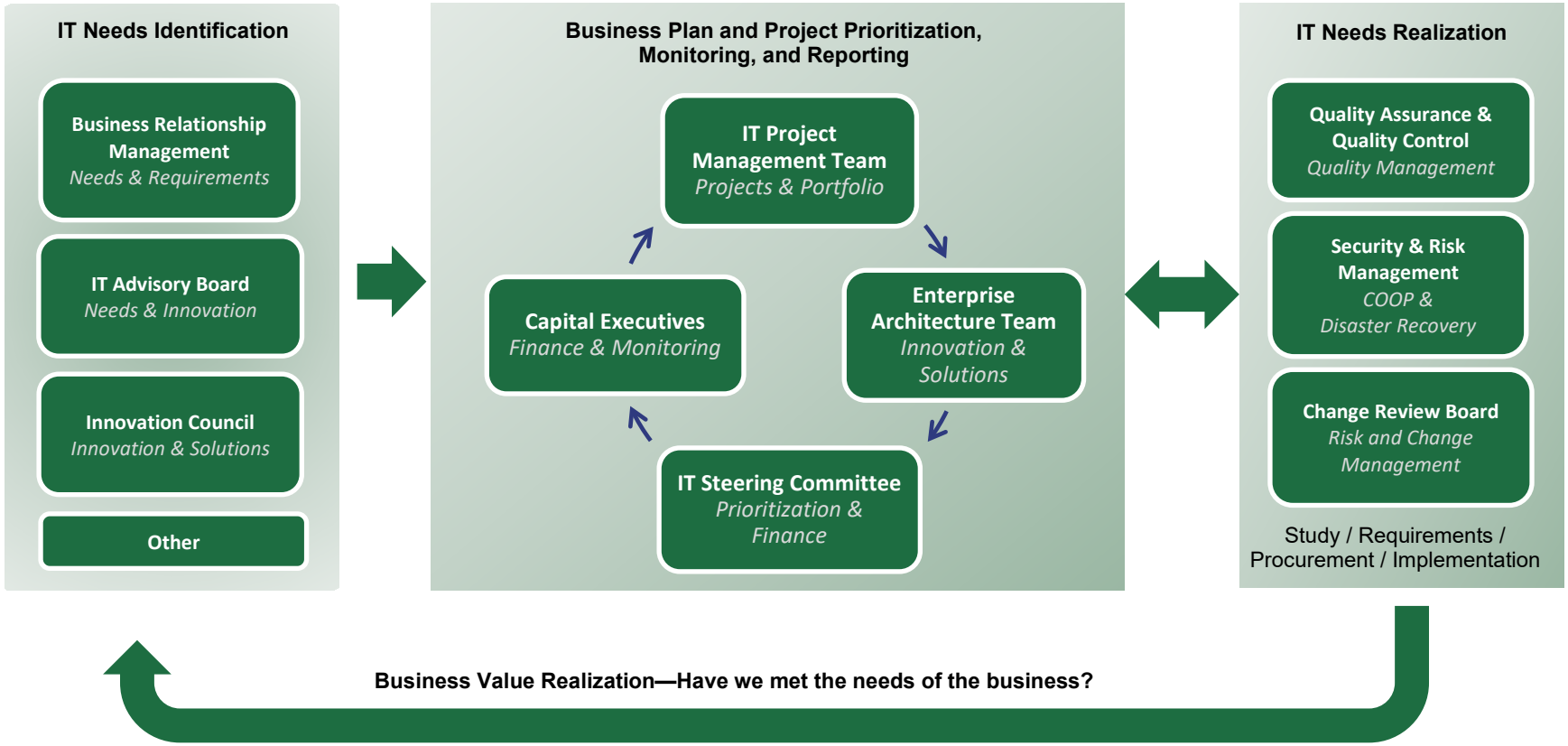


**Figure 2. Flow chart. Pennsylvania Turnpike's technology planning approach.**
(Source: R. Taylor, Pennsylvania Turnpike Commission.)

- **Develop long-range IT-TSMO framework—**TSMO related IT resource needs can be identified and formally documented in a long-range IT-TSMO framework to provide both groups a guide for future needs. This framework can include known equipment and software needs (new or replacement), IT services or functions, and any planned or recurring maintenance efforts. Input within the framework can then be used to determine adequate internal staffing, as well as funding to cover continuous.
- **Develop IT policies that support TSMO—**IT policies are developed for a wide range of efforts; they are often established at the Statewide level and may not adequately recognize the unique TSMO operational environment as related to staffing (such as 24/7 overtime) outsourcing, use of pre-approved equipment, software, and vendors. In addition, TSMO may introduce specific risk management features not otherwise identified attract within the IT operation.

**Coordinate TSMO and IT Strategic Plans**

To manage IT across the entire State, the Connecticut IT Division develops customer-specific five-year IT plans based on each agency's objectives. The plans include defining technology needs and priorities, identifying funding sources (or gaps), and aligning business goals and initiatives with technology solutions.

## Program Delivery Practices

TSMO has its own characteristic project delivery cycle—each of which may have an IT component. These practices help ensure active IT involvement with project planning, technical reviews, and procurement.

### *Program Delivery General Principles*

*Involve Information Technology Personnel in Project Delivery Teams*

TSMO project delivery teams have comprised a wide range of subject matter experts, typically covering traffic operations, traffic safety, ITS, and traffic incident management and others.

The additional involvement of IT staff in project delivery can help ensure that State and agency policies relating to hardware, networking, and data management are followed. This involvement can also serve to speed or streamline the project delivery process because many of the primary groups who could have a say in the project would be represented on the team. It can also serve to build and cement relationships between IT and TSMO staffs by providing an opportunity to learn more about each other's needs and work processes.

*Use of Lifecycle Cost Models*

TSMO projects typically involve long-term operational staffing, equipment costs, and maintenance activities that agencies account for and program. Input from both TSMO and IT groups—based on historical data for staffing effort, equipment costs, maintenance cycles, and effective lifespan of hardware and software—are important inputs to both TSMO and IT

business planning and budgeting efforts. Future project resources and costs can be incorporated into annual operating costs for the respective owner and be coordinated with any system maintenance efforts. Properly considering project resources can insure smooth TSMO program delivery.

**Develop Lifecycle Costs**

The costs to deploy and maintain IT-TSMO systems are often significant and require annual resources, both in terms of staffing and maintenance. In many cases, over time, various groups deploy TSMO technology without considering product lifecycle, technical support, or replacement costs.

PennDOT developed an approach to evaluate their IT and ITS investments from a holistic lifecycle cost perspective. The largest hurdle involved in the lifecycle approach was inventorying everything in the field and understanding what was installed, what purpose it was serving, and how it related to other features. This required a systems approach to map out the inventory from the software platform to various network connections to field devices.

While the cost of staff resources who maintain and service the equipment increases with the number of assets installed, each PennDOT District also had preferred vendors and manufacturers. The preferences often differed by district, resulting in several different devices and systems across the State providing the same function. Consequently, staff and budget constraints within Penn DOT prevented IT from supporting the number and variety of devices and systems. As a solution, PennDOT simplified the number of available manufacturers and required projects to remain within the standards to increase the efficiencies within the IT group and ultimately reduce recurring costs.

From the reverse perspective, adding technology to automate functions can also be beneficial to the lifecycle cost. PennDOT identified value in providing communication to traffic signal corridors and allowing remote connectivity. The increased upfront investment in technology offset the ongoing time investment for managing the signals and resulted in an overall cost savings, because staff could modify timing remotely.

### *Program Delivery—Specific Practices*

This project identifies four specific practices with broad applicability across several challenges as indicated in the challenge-driven section above:

- **Incorporate IT staff in systems engineering process—**While the systems engineering process does involve the design of hardware and software systems, it also involves systems integration, testing, and verification, which rely heavily on IT staff. The sequence of standard steps can be conducted specifically to provide multiple checkpoints for coordination with IT during project development. IT partners also add value to the process through expertise on operations, maintenance, and eventual upgrade, replacement, or retirement.

- **Establish TSMO approved product list—**Many agencies use the same TSMO and IT products either in new installations or replacement activities. Developing an approved products list that complies with the jurisdiction's procurement laws and regulations for recurrent purchases can reduce the procurement time for common TSMO equipment. In addition, prequalifying products can help reduce delivery time by eliminating or reducing the time required for research, evaluation, or approval—by either TSMO or IT staff as appropriate.
- **Adjust procurement process for TSMO—**State and local procurement rules and processes vary, and agencies can identify the best approach for TSMO and IT efforts that complies with their jurisdiction's laws and regulations, given the required type of equipment or service that may be differentiated by scale (costs) complexity, continuity, use of proprietary technology etc. Cooperation between TSMO and IT staffs can make it possible to select the most appropriate methods within the jurisdiction's procurement rules and processes.
- **Establish IT-TSMO project review—**Complex technology projects, where a full systems engineering approach is utilized, can include reviews by TSMO and IT participants. For smaller projects, an abbreviated review may be appropriate. These processes can include standard checklists and documented approvals by those TSMO and ITS staff members who review authority within their respective groups or units.

**Equipment/Systems**

TSMO systems and equipment rely on certain specific procedures to ensure functionality. These identified practices are wide ranging, from establishing security systems and improving communication infrastructure to data sharing and data management.

***Equipment/Systems General Principles***

*Maintain an Intelligent Transportation Systems Architecture*

ITS architectures provide a high-level framework that illustrate how existing and planned ITS elements interconnect and interface to exchange information and collectively deliver transportation services and functions. The development of the ITS architecture can include the agencies that have a role in the various systems to ensure consensus among the owners and users. Within each agency, the involvement of IT staff in ITS architecture activities can increase mutual understanding of the system requirements, data needs, communication, and security.

Agencies may undertake periodic reviews and updates to keep the architecture relevant with new services and emerging technologies.

*Improve Data Communications Infrastructure*

Newer technology systems provide increased surveillance, data, and analysis but generate and use significantly more data, both in terms of volume and velocity. Therefore, the functionality of technology systems relies on data transmission. The health of the data communications infrastructure is critical to reliable operations—including considerations of capacity, reliability and redundancy, and security. The network evaluation and improvement can extend beyond a

single agency. Options for infrastructure sharing with neighboring agencies, public-private partnerships, and lease lines can improve network reliability at a reduced or shared cost.

### *Equipment and Systems—Specific Practices*

This project identifies four specific practices with broad applicability across several challenges, as indicated in the Challenges section:

- **Develop an integrated security system with IT staff—**An information security system can be part of an overall risk management program and include both physical and electronic risks to the TSMO functions. A formal, documented risk assessment can be prepared with IT staff that identifies potential threats and vulnerabilities, their associated probability, and potential impact. An integrated security system may need to be modified from traditional or enterprise IT security requirements. TSMO and IT staffs can evaluate the implications of the various system configurations and determine the impact to functionality, security, staffing, and convenience.

**Joint IT-TSMO Cybersecurity Risk Management Exercise**

Michigan DOT's ITS Program Office wanted to assess the cybersecurity vulnerability of their ITS network. They found it was difficult and expensive to get their maintenance contractor to provide this service. Instead, they worked with the State of Michigan DTMB cybersecurity group and had them analyze their networks. DTMB identified cyber risks and informed MDOT about the vulnerabilities. MDOT now has robust rules and firewalls to keep operations networks and enterprise networks secure.

DTMB also identified risks with partner agencies that share the MDOT network. The partner agencies do not have the same in-house expertise that MDOT has with DTMB. Partner agencies may not be able to mitigate the identified security risks and vulnerabilities that were identified, but they are aware of them and MDOT has acknowledged those risks. MDOT may be able to use the DTMB equipment to analyze the network again in the future.

- **Establish necessary decision support systems—**Decision support systems provide analytical tools that utilize available data to reach an operational decision that supports the TSMO objectives ranging from automated real-time systems to offline manual systems. Including IT resources during the development of decision support systems may expand capabilities for data mining, analysis, visualization, and process automation.
- **Define and coordinate data sharing and access agreements—**Shared access within a technology platform can increase the functionality of the system by allowing wider use, more timely operation, or other factors. External agencies may access a platform to observe operations, control the system, extract data, or other purposes. It is good practice for shared access to be mutually agreed upon and for associated access agreements between the parties to clarify access rights, restrictions, and security protocols. Associated data-sharing agreements between the parties can clarify the data source, data type or format, delivery method, and appropriate security and sharing restrictions.

- **Create a data governance and management plan—**Technology systems generate a significant amount of data that may create a challenge for agencies to manage and control. A data management plan can be used to identify how data is collected, organized, stored, and archived. Because much of this calls for database management, it is important that IT resources are involved early in the process to determine appropriate process and analytics, data sources, formats, storage location, as well as data access, ownership, version control, integrity, quality, control, and security protocols. Formally documenting the data management efforts can help TSMO and IT staffs operate more efficiently and assist during staff turnover.

# CHAPTER 4. APPLYING INFORMATION TECHNOLOGY AND TSMO INTERACTION PRINCIPALS TO EMERGING ISSUES

Powered by an increased focus on performance management, Transportation Systems Management and Operations (TSMO) has become a major formal program element in State departments of transportation (DOT). As documented throughout this report, the role of information technology (IT) in TSMO is becoming ever more pervasive as the extent and complexity of information technology in TSMO strategies increases. Agencies are integrating TSMO strategy applications into a widespread, complex, and dynamic system that depends on:

- High-speed networks and related digital and video communication technologies.
- A range of sophisticated surveillance and detection devices.
- Management centers utilizing specialized analytics backed by artificial intelligence (AI).
- A wide range of big data sources.
- Growth in the in inventory of supporting hardware and software.

Taken together, these systems make heavy demands on IT-related resources including hardware maintenance, software support, IT network management, and communication media knowledge. There will be an increasing need for expertise in issues related to procurement, security standards and practices, and system maintenance. These demands and needs are reflected in the full range of challenges discussed in chapter 3.

As described in chapter 2, the last 10 to 15 years have seen the first initiatives to integrate the concerns of IT into TSMO at different levels and follow different paths, reflecting differences among transportation programs and statewide IT policies. The lessons learned are mirrored in a wide range of practices in response to challenges experienced.

However, the state of play described in this report represents a simple snapshot in time. The TSMO and IT domains are both subject to rapid technology change, complicated by the evolution of the institutional environment.

**TSMO technology and applications—**Much of the systems and technology of tomorrow in which TSMO relies significantly on IT is already visible in the more advanced agencies. At the time of this publication, many products and services are in development phases or limited pilot applications to test the viability and business need. These emerging technology and application trends include:

- A growing toolkit of AI technologies, including computer vision, natural conversation, and machine learning for decision support.
- Broader band and higher speed communications (5G cellular).
- Reliance on edge computing.
- Distributed hardware and networks.
- Big(ger) data.
- Mobile access.

Not only is the technology complex, so are the applications, products, and services often involving non-infrastructure components and external players, both public and private, including:

- Connected and automated vehicle (CAV) integration.
- Electronic road pricing (road usage charging).
- V2X communications.
- Custom-focused mobility as a service.
- Smart Cities and the Internet of Things (IoT).

**IT focus—**Information technology is an increasing component across the full range of governmental agencies—not just transportation—and their functions, which include improving the business processes of State agencies to increase their effectiveness and efficiency, ensuring cost-effective value driven IT-related asset investments, and supporting data and information security standards.

TSMO and IT intersect across each of these functions. However, as noted in chapter 2, the TSMO domain has several unique characteristics that call for custom tailored accommodation regarding system availability, data governance, procurement, security, and system maintenance.

**IT-TSMO institutional relationships—**Just as TSMO and IT technologies are evolving, so too are the relationships between the TSMO and IT domains, including business and technical processes and supporting institutional arrangements. As documented in this report, there is no standard approach to integrating IT expertise into TSMO program activities. Approaches range from using transportation agency dedicated IT staff to relying on a separate State agency and every level of integration in between. Each of these approaches offers differing opportunities to recruit qualified staff, stay current with the latest technology, leverage respective skill sets, and gain advantages in procuring and maintaining IT infrastructure.

**A long-term perspective—**Many of these emerging technologies have not gained mainstream adoption. In addition, coordination, communication, and organizational practices are in early stages of development and vary widely across States.

As indicated in the research and agency outreach efforts that formed the basis of this publication, there is a modest inventory of practices that in themselves do not yet reflect long-term or widespread experience or feedback on these systems. This is especially true in the "cutting edge" areas of new systems and technologies.

As early adopters become more experienced and more agencies deploy the technology, there will be more insight and practices to assist the IT and TSMO communities. In the interim, many of the practices identified by agencies in chapter 3 help to prepare for unknown future technologies and applications.

**Fundamental principles to ensure sustained coordination—**Notwithstanding the evolving nature of technology and institutional configurations that affect the relationship between the TSMO and IT domains, the experience to date suggests that several "technology-neutral" core

principles can be used to form a solid foundation for IT and TSMO collaboration ahead of emerging technologies or to address challenges encountered when implementing emerging technologies. Whether agencies employ these practices preventively or in real time, the key principles strengthen the working relationship between the groups and can reduce potential challenges and minimize risks.

Key principles fall into five areas:

- TSMO and Information Technology Collaboration.
- Technical Capability and Staffing.
- Planning and Programming.
- Program Delivery.
- Equipment and Systems.

## TSMO AND INFORMATION TECHNOLOGY COLLABORATION

A high degree of collaboration is essential between the TSMO and IT disciplines and expertise to support TSMO, especially in the light of increasing systems and technology complexity. The need to develop a high degree of communication and coordination is therefore fundamental. Context-neutral key principles supporting collaboration include:

- Understand the respective domains' fundamental objectives and systems, including willingness to "educate" respective staffs and domain functions and constraints.
- Define key responsibilities as they relate to the role of IT within TSMO and related organizational arrangements, including flexibility to experiment and/or adjust as programs evolve.
- Recognize differential roles of IT throughout the entire TSMO project lifecycle from planning through design procurement deployment and system maintenance.
- Provide flexible organizational configuration to adjust responsibilities that consider TSMO versus IT staff technical expertise.
- Retain flexible organizational configuration to adjust responsibilities that consider special demands of certain TSMO projects.
- Formalize agreements regarding objectives, priorities, roles, and responsibilities to ensure sustainable collaboration and to face changing staffing and context.

## TECHNICAL CAPABILITY AND STAFFING

TSMO systems, technologies and institutional relationships are becoming increasingly complex. The critical challenge to TSMO programs (and to IT staff supporting TSMO) is to access and retain the appropriate staff technical capabilities, especially in new areas such as AI, data management, cloud computing, and analytics. In addition, as both TSMO and IT programs expand, workloads and staffing requirements are also growing. Context-neutral principles include:

- Identify essential core staff technical and management capacity for TSMO (in terms of knowledge, skills, and abilities (KSA)).
- Use pilot programs to identify needed expertise and sources, internal and external.
- Consider appropriately locating needed IT expertise for TSMO, within TSMO versus IT groups.
- Identify currently available training resources, internal and external.
- Focus recruitment on both internal transfers and potential broad range of external "pools" of qualified candidates.
- Consider appropriate roles of outsourcing for capabilities or services—dependent on practicality and cost-effectiveness of maintaining specialized expertise—and where possible, consider the use of outsourcing as an opportunity to gain expertise for possible in-house transfer.
- Recognize that specialized expertise and/or services may be best accessed by public-private partnerships, and that specialized management of such arrangements is a needed capability.

**PLANNING AND PROGRAMMING**

As TSMO programs become more extensive, complex, and costly, and as they involve a wider range of assets that may be supported by IT or subject to IT policy, it is increasingly important for TSMO planning and programming to involve IT from the outset. In addition, agencies have found that special features of TSMO systems and assets, such as availability, field hardening, and short lifecycles need to be accommodated with IT interests from the beginning. Context-neutral principles include:

- Conduct formal TSMO planning within the transportation agency context to ensure access to the full range of DOT and IT funding resources.
- Recognize explicit IT principles' constraints.
- Involve IT staff in formal planning to ensure availability of needed IT funding resources.
- Track both TSMO and IT private-sector developments to maintain state-of-the-practice relevance.
- Involve IT staff in systems engineering to ensure broad understanding of systems and IT-related roles and responsibilities.
- Accommodate technology and analytics updates for increasingly ATM.
- Utilize lifecycle approach to ensure mutual IT-TSMO understanding of system maintenance challenges.

**PROGRAM DELIVERY**

TSMO program development depends substantially on combinations of public- and private-sector infrastructure, devices, and services. "Projects" may include a mix of communications, devices, hardware and software, and fixed assets, separately or in combination. These projects are in many respects distinct from conventional State DOT assets and related project

development practices. In addition, technologies are rapidly evolving and may be proprietary, and involve risks of operationality and obsolescence. As a result, while the investment levels may not be large compared to other transportation assets, the project development process has unique and often complex features. Context-neutral principles include:

- Define appropriate project development process that includes input; reviews can be obtained from the appropriate IT and TSMO staff.
- Utilize systems engineering approach to ensure that all hardware and software requirements have been identified, including roles and responsibilities of key parties: TSMO, IT, and external.
- Utilize lifecycle approach to ensure that the key cost elements from implementation to long-term operational maintenance activities have been accommodated.
- Investigate the full range of potential procurement options for various projects as appropriate, including any IT-related constraints.
- Continue to review project development process for opportunities to streamline, including early involvement of IT staff review.

**EQUIPMENT AND SYSTEMS**

TSMO projects often involve complex combinations of communication, surveillance, control, analytical, and computing technologies. TSMO projects may also include operational dependence on external parties or systems for information or services. Context-neutral principles include:

- Maintain systems architecture to ensure consistency and interoperability.
- Produce data management plan, including considering external data resources, remote processing and sharing real-time data.
- Develop effective, standardized, and efficient approaches to managing relationships with external private-sector entities that supply technology or services.
- Update TSMO security systems with IT staff so that the security protocols align and support the newer technologies, including firewalls, administrative rights, and software access.

# APPENDIX A. COMMON CHALLENGES IN COORDINATING TSMO AND INFORMATION TECHNOLOGY

This appendix describes the common challenges experienced by Transportation Systems Management and Operations (TSMO) and Information Technology (IT) groups working together within a transportation agency that were identified through the project research. The individual challenges are categorized within functional groups based on common issues and all groupings are further categorized into two large classes: institutional challenges and business and technical challenges. Where feasible, specific agency examples are provided for individual challenges based on interviews and outreach efforts.

## A.1. INSTITUTIONAL CHALLENGES

The interaction between TSMO staff and IT staff is often influenced by the organization itself, including professional culture, organizational structure, staff capabilities, and resource allocation. Challenges can arise when the organization's history, the underlying culture of its staff, or the available resources do not align with the current mission or task. Common institutional challenges can be encountered at all levels of the organization from leadership decision-making to frontline implementation.

### A.1.1. Culture

This subsection discusses common challenges related to professional culture. Culture consists of the values and behaviors that influence personal relationships or interactions between the differing agency functions or groups.

#### *Culture-1: Lack of Mutual Understanding between TSMO and IT Staff*

TSMO units and IT units, like many areas within a transportation agency, are separate not only in function but also in location. The physical and functional separation can limit interaction and ultimately limit the understanding and familiarity of the other unit. Staff shortages in some agencies can further distance the groups by reducing the available time to meet and coordinate. While several of these contributing factors are addressed individually in other challenge areas, the resulting lack of mutual understanding is a common challenge that inhibits progress.

During normal business, TSMO staff is focused on optimizing traffic operations and ensuring traffic safety. These functions are external in nature and employ various technology platforms to monitor, manage, and communicate with drivers. In delivering these functions, TSMO staff may perceive IT staff strictly as internal technical support who may be able to quickly assess and resolve any technical shortcomings during crises. TSMO staff may not understand the backlog of other agency IT functions or the complexity involved in resolving a malfunctioning technology system.

Conversely, IT staff is responsible for building and maintaining a vast array of business platforms (hardware and software) across many functional areas within an agency. While IT staff is focused on delivering service to their agency customers, they may not appreciate the urgency involved in TSMO functions. TSMO functions are directly linked to public safety, and an IT malfunction may have significant impacts on vital traffic management functions. IT staff may

not understand the public safety ramifications of TSMO-related systems being inoperative for an extended timeframe.

As an example, the research identified one agency in which the priorities between the State department of transportation (DOT) and their central IT group were not always aligned on project implementation and maintenance needs of new technology. While the overall lack of understanding in this case was largely attributed to staffing constraints and a shortage of time to coordinate, there was a strong recognition and desire to increase mutual understanding.

### *Culture-2: Lack of IT Staff Availability when TSMO Staff Need IT Support*

TSMO functions, by definition, center around the management and operations of transportation systems ranging from freeways to arterials to transit. These environments operate 24 hours per day and (typically) do not have downtime. As such, the underlying systems that monitor and manage the operations can also be available and function 24 hours per day. Agencies have found that any issues with these systems need to be resolved expeditiously to avoid potential issues with traffic safety or efficiency across major transportation infrastructure.

Traditional agency staff, including most IT units, work during typical business hours, Monday through Friday. This traditional schedule may be satisfactory for many agency functions that have long-lead projects, but a strict adherence to this schedule may limit support during evening or night and weekend hours when TSMO functions are equally critical as normal weekday hours.

TSMO functions are also continuous operations rather than stand-alone projects. As such, agencies have found that systems requiring updates or repair need to minimize downtime to the extent possible. While planning these upgrades can be possible, some updates or repairs may be unplanned and urgent with little to no notice. An orderly response to providing support and resources to these unplanned issues may not be feasible through a ticketing method or first-in, first-out approach.

As an example, one TSMO group that participated in the agency outreach effort of this project highlighted the fact that their Statewide IT unit was not accustomed to supporting a real-time 24/7/365 business such as TSMO, which operates continuously. This lack of available support was especially evident during times of regional or Statewide weather events and on State holidays.

### *Culture-3: Different Staff Backgrounds and Roles Lead to Silos*

TSMO and IT staff typically come from very different backgrounds and career paths. Both units are diverse and include many different staffing roles, but in general, TSMO staff are traffic engineers or technicians, while IT staff are computer or systems engineers.

Traditional education and career paths for TSMO staff are focused on civil engineering or the built environment. This perspective on public infrastructure is highlighted through delivering safety and efficiency in physical resources. Within TSMO, the focus is more directed at safe and efficient operations of the transportation system.

Traditional education and career paths for IT staff are focused on computer science and information management. This includes computer and network equipment, software development, and database management that are scalable and replicable. With further emerging technology services and applications, many of these systems can also be virtual and located remotely.

These differing backgrounds and skillsets can result in silos when the IT and TSMO functions overlap. These silos can lead to inefficiencies or solutions that do not take full advantage of available technology. One example is that TSMO staff often develop communications network to transfer data and video to and from the field devices back to a central hub. This can lead to inefficiencies in overall network operation. IT staff is more likely to develop the network from the "top down" taking advantage of the best centralized equipment for the network and then building to the field equipment. Middle switches and edge switches can be matched with the latest central equipment.

***Culture-4: Shared Resources and References for TSMO Related IT Needs Are Scarce***

Technology has served the TSMO sector for several decades but has undergone drastic changes in the recent past. The rate of change in available types and volume of available TSMO data and the systems needed to collect and analyze this data are increasing. Agencies have responded to these new technologies based on their individual capacities and internal lessons learned.

There are few national resources or reference guides available to assist agencies in navigating the IT requirements for TSMO. One reason may be the lack of an organizational body dedicated to research and practice within the overlap of both TSMO and IT. Another reason may be the speed at which technology is changing compared to the time required to publish material.

The limited amount of shared knowledge often leads agencies to repeat approaches taken by others and learn similar lessons without the awareness of the commonalities. The lack of reference material can also slow the adoption of newer approaches that may increase depth and breadth of services.

### A.1.2. Staff and Financial Resources

This subsection discusses common challenges associated with staff and financial resources. Staffing and financial resources are essential components to fulfilling TSMO and IT needs and are required for nearly all aspects of acquisition, development, and maintenance of IT systems.

***Resource-1: Funding Sources for IT-TSMO Projects Are Not Well Established***

While TSMO as a stand-alone function or group has gained significant traction in recent years, funding sources within State DOTs have not kept pace. Many established TSMO groups have dedicated funding for staff, operations, and maintenance of existing features but encounter difficulties identifying funding sources for new projects or efforts.

Agency programming and funding allocations have traditionally been centered around infrastructure and capital investments. Most projects—whether planning, design, or maintenance—have an element that supports constructing or rehabilitating "external" physical

assets, and TSMO intelligent transportation systems (ITS) field elements can typically fit within these parameters. However, ongoing funding for maintenance and operations of the new features is often not included in these programs, and other sources are needed for future sustainability.

TSMO efforts that predominately center on software, data, networking, or other "internal" technology platforms often encounter constraints in funding. Significant portions of transportation funds are strictly allocated within an agency's program. If allowable funding is identified, it is typically not dedicated or recurring and TSMO efforts will likely have to compete against other priorities.

As an example, the research identified one agency in which securing funding for TSMO technology projects was problematic. The justification for funds was particularly difficult for this group as the policy-makers did not recognize the importance of the IT elements within TSMO projects. IT elements are generally hidden components that may not be readily visible. This type of problem can apply specifically to expenditures to upgrade communication networks and replace network devices, operator workstations and video walls, and a variety of maintenance equipment to enhance network or device troubleshooting.

### *Resource-2: Recruiting and Retaining IT Staff is Difficult with Competition from the Private Sector*

IT has become integral to nearly all aspects of the modern world. Data, computing, communication, and advanced analytics are commonplace in most industries, and the demand for talent has followed. Professionals who specialize in IT are highly sought after, and demand is forecast to remain high.

Public agencies that rely on IT professionals compete with private industry, which has a different and competing business model for staff. Private companies, operating on behalf of shareholders or owners, typically offer higher salaries, bonuses, and more flexibility, both in terms of hours and location. Public agencies, operating on behalf of the taxpayers, are typically constrained in terms of salaries, location, and hours.

For many agencies, retaining IT staff is as challenging as hiring. The IT industry is ever evolving, and external opportunities can entice staff if they do not see future opportunities to grow internally. Like any industry, staff turnover can also occur once the individuals have been trained and gain experience.

As an example, one TSMO group that participated in the agency outreach effort of this project highlighted the fact that staffing was their top priority. Recruiting for this group had been an issue due to pay levels not being competitive with the market and the restrictions created by the position classifications. Due to the poor pay structure, it was common for staff to leave after a few years once they obtained training and marketable technology skills.

### *Resource-3: Training Requirements and Programs for TSMO Staff and IT Staff Are Not Typically Provided Internally*

Agency-wide training programs mostly focus on general administrative and safety protocols such as building safety (fire, etc.), working within public right-of-way, computer basics, and similar

topics. These training programs are developed to ensure basic understanding across large numbers of staff and to minimize agency risk. Specialized internal training is typically developed for the largest contingencies and common practices—for transportation agencies, these may include construction practices, traffic control, and maintenance protocol.

TSMO and IT are both typically smaller units within a transportation agency and established training programs are not common. External training options are available, but there are few standards on what an agency would require, and there may not be requirements established by position (knowledge, skills, abilities [KSA]). In addition, registering for external training typically requires initiation by the individual or manager and approval for funding. Because these trainings are not required, requests may require special justification and may not be supported on a wide scale (or may be considered personal education and the responsibility of the individual).

The breadth of topics within TSMO and IT are significant and not necessarily standardized across either industry. Staff looking for external training may have difficulty finding training programs specific to the public agency environment or their role. It is more common for staff to select specific training related to a task or project as the need arises.

#### *Resource-4: Use of Private Firms to Provide Services Requires Funding, Long-Range Planning, Strict Oversight, and Approval*

As agencies consider options to adequately support IT needs, some have explored or implemented external services to bolster resources. The reasons to employ private services can vary, but agencies may find that they need an increase in the knowledge base, manpower (number of staff), or availability (specific timeframe or temporary assignment). Other reasons to outsource may be directed by political or funding constraints.

The use of private firms can be beneficial but are typically more expensive on a per-hour basis. In addition to the direct costs of the external staff, indirect costs—such as oversight for contracting, invoicing, supervision, and quality control—are often incurred. These costs require a funding source that can support the additional staff for the duration of the need, whether short term or long term. Inadequate funding can result in disrupting projects or gaps in operations.

### A.1.3. Organizational Structure

This subsection discusses common challenges related to organizational structure. Organizational structure includes the formal and informal structural arrangements around which staffing, roles, and responsibilities are managed and carried out.

#### *Org-1: TSMO is Limited in its Direct Interaction with IT Leadership Given the Hierarchical Structure*

Each State has its individual organizational structure that could include IT units within a State DOT or not. In States where the IT unit is outside the State DOT, interaction may be limited due to the organizational and physical separation.

Consolidating IT services across an entire public agency into a single enterprise group creates efficiencies in managing resources and consistency across the agency. However, it can also limit

the interaction between units and cause them to be more transactional. For TSMO, the separation may result in reduced formal and informal coordination and limit the ability to build strategic partnerships or planning efforts that are critical for technology systems that support continuous transportation operations.

### *Org-2: Lack of Clarity in Defining the Roles of Departments of Transportation IT Organizations Versus the Enterprise IT Organization and Associated IT Ownership*

Enterprise groups are designed to maximize efficiencies in technology infrastructure, software platforms, services, and staffing through integration and replication. However, those efficiencies may not be applicable within a DOT/TSMO unit and some States (e.g., Tennessee and Washington) have maintained separate IT units within individual agencies in addition to the centralized IT office or department. This can provide more local support but lead to confusion over the differing roles and ownership.

The larger centralized IT office or department and smaller DOT-focused IT unit typically have overlapping technical capabilities and functions. The result may be confusion over which group has authority on purchasing, staffing, and service, as well as ownership of the system or data. Without clearly defining specific roles, the IT units and their clients may not understand the correct methods to obtain resources. In addition, the enterprise group may set requirements for the individual IT units to obtain permissions prior to specific actions, which may add unnecessary levels of approval and slow implementation.

### *Org-3: Organizational IT Capability Varies Across the State and is Often Weaker in Rural Areas*

Statewide agencies typically have large geographic areas to manage and operate, which results in district or remote offices (or campuses). These district or remote offices maintain local staff or resources where needed and provide a more direct link to the local community. However, these smaller locations may focus on resources required for local infrastructure (construction and maintenance) and not contain all support services necessary to maintain the organization, such as IT staff, particularly when the offices are small and located in rural areas.

Like many administrative or business functions, IT services are often centralized in a headquarters location for various benefits. There are efficiencies to providing agency-wide support from a single, cohesive group that is co-located and managed. The shared resources can be deployed to district or remote offices as needed, and costs can be balanced between locations that may not require full-time staff. The larger headquarters group, or an IT group in a larger district office located in an urban area, typically benefit from a larger talent pool as well, which increases the number of quality candidates.

The challenges associated with a centralized headquarter IT group are largely associated with availability. IT staff are not readily available due to travel requirements and competing locations, and there may be significant delays involved in obtaining onsite service (though remote logins are possible for diagnosis and software-related issues). Rotating staff assigned from a centralized group may also result in unfamiliarity of the local technology systems, particularly if there is any customization.

As an example, the research identified one agency in which the larger metropolitan offices were able to benefit from greater talent pools and maintain stronger staff capabilities in the technology fields. However, the more rural offices lacked candidates with similar skills, and the technology capabilities in those locations were reduced and uneven.

### *Org-4: Approval Processes are Challenging for the Unique Environment and Function of TSMO*

To minimize risk, many agencies have implemented formal approval processes to ensure that technology purchases and implementation follow standard protocols and have been vetted by IT leadership. To maintain control over the processes, there is often little delegation of authority, meaning a few individuals can delay the entire process due to availability or other issues.

Technologies used for TSMO functions are typically not standard enterprise IT solutions and therefore may involve further evaluation and justification. Depending on the level of review specified and how rigid the internal policies are set, this additional step may involve significant effort. Strict adherence to the same procedures used to evaluate enterprise applications may prevent or significantly delay adopting newer solutions specific to TSMO.

As an example, the research identified one agency in which the IT department processes were very rule-driven and lacked a high level of delegation, which created significant delays to budget approvals and project delivery because TSMO did not fall into traditional IT definitions. For this TSMO group to obtain internal IT approvals, project champions were assigned to provide the IT department with specific justifications to gain exemptions and approval.

### *Org-5: Meeting Expectations and Needs Can Be Challenging When Operating Key Business (IT) Resources is the Responsibility of a Separate Organizational Unit*

The division of responsibilities within an agency's organizational structure is often necessary to efficiently manage resources. It is common for TSMO and IT functions to be in different areas within an organizational structure due to their differing focus and skillsets. A dependent, working relationship is created when ownership (or management) of a technology system within TSMO is assigned to the IT unit.

Staff at all levels influence the relationship between separate divisions, groups, or units. Poorly identifying and communicating expectations and needs can affect business operations and performance at all levels. A lack of planning and coordination by frontline staff may result in increased pressure for resources.

This situation can also present itself in shared environments, where two or more external governments share the responsibility of common or adjacent infrastructure or operations. For instance, an owner-agency responsible for freeway operations may transfer oversight of the interchange traffic signals to the local agency who is vested in arterial operations across the freeway. These transfers of responsibilities are often formally documented through intergovernmental agreements but could also be nonbinding through more informal arrangements.

### A.1.4. Policy

This subsection discusses common challenges related to policy. Policy includes legislation and regulations, executive-level directives, departmental policy, or requirements that are not directly targeted to TSMO or are outside the departments or divisions of either IT or TSMO.

#### *Policy-1: TSMO Design, Procurement or Operations are Affected by Policy*

Transportation agencies must operate within legislative and policy frameworks of their respective jurisdictions. Some legislation is directed specifically toward transportation agencies and is conceived of and developed with specific transportation policy issues in mind. However, sometimes more general legislation affects transportation agencies in more indirect ways. Centralizing IT resources in a single department can affect transportation agencies even though the legislation is not specifically directed at transportation agencies.

Centralizing IT resources can present challenges because the centralized IT staff may not understand not only the unique environment, requirements, systems, and devices that are needed for TSMO strategies, but also the transportation business at a higher level.

In general, TSMO staff may encounter legislation that makes their normal methods of doing business challenging and may even make conforming to the legislation challenging while meeting budgets, schedules, and other commitments.

#### *Policy-2: TSMO Procurement Processes Can Be Affected by Jurisdiction Level IT Procurement Rules*

Many devices, services, and systems needed to implement TSMO-related strategies are considered IT elements that may be required to follow jurisdiction (for example State, county, or city) IT procurement rules. These rules are generally based on the legislation mentioned in challenge Policy-1 above. These rules are often promulgated to implement legislation. Some of the rules have been in place for many years. In many cases, the rules were developed considering traditional enterprise IT devices, services, and systems. The environment for the systems and devices is usually inside a building. The functions that were the focus of the rules tend to include financial management, human resource, data management and reporting, and agency-level communication systems (both voice and data). The procurement rules may not have been developed considering transportation field devices or transportation management or maintenance systems. With more technology integrated in transportation devices, the expansion of sophisticated software systems, and the increased amount of data that needs to be managed, TSMO-related procurement increasingly falls under IT procurement rules.

Historically, transportation agency procurement rules for field devices and systems that communicate with and control them have developed to be in line with procurement of other transportation services and items, most notably construction, equipment (such as vehicles, signs, or material), and professional services. The requirements and processes for traditional transportation procurement and those for IT procurement differ and may not be compatible. The challenge for TSMO staff is to navigate the two sets of procurement rules to determine which take precedence and how best to utilize the most appropriate rules for each procurement. (FHWA developed a memo clarifying the distinction between operational improvements and ITS

construction as it relates to procurement options: Procurement and Authorization of Federal-Aid Operational Improvements (Non-Construction Projects.)

## A.2. BUSINESS AND TECHNICAL CHALLENGES

Implementing technology within an agency can be affected by the business and technical processes associated with developing systems, including planning, procurement, cybersecurity, and data management. Challenges can arise when processes that worked well before the proliferation of IT systems and devices are not suited to addressing the particular needs of TSMO or IT organizations. In other situations, processes may have been developed in isolation within either the TSMO or IT organizations and worked well if the organizations remained isolated. Common business and technical challenges could be encountered at any stage of project activity or development.

### A.2.1. Strategic Planning

This subsection discusses common challenges related to strategic planning. Strategic planning includes the vision, mission, and objectives of the different organizations and functions and the integrating each in overall agency planning and resource allocation.

#### *Planning-1: Strategic Plans and Governing Mission, Vision, and Goals Can Differ Between TSMO and IT*

Agencies, and departments or divisions within the agencies, typically develop long-range strategic plans that guide policy, practice, and funding decisions. These strategic plans are usually prepared internal to the groups, and while they may consider outside needs and services, they may not be coordinated or integrated at a high level.

TSMO strategic plans are generally centered around external factors related to traffic operations and safety. The mission, vision, and goals are based on external performance measures (mobility, reliability, crashes) and supporting resources (staff, training, infrastructure). While a TSMO strategic plan may include supporting IT resources, these goals or needs are not communicated to or incorporated into the IT group's strategic planning efforts.

The gap in coordinated strategic plans can ultimately create gaps in funding and programming efforts when goals shift to actions.

#### *Planning-2: Programming and Development of TSMO IT Projects Does Not Align with Traditional Construction or IT Projects*

Several IT-based projects or efforts that support TSMO are unique and do not align with traditional agency programs. These types of projects do not fit within the most common project development model centered around infrastructure construction—design (consultant) followed by build (contractor). They also may not fit within traditional IT efforts, which may focus on procurement of stand-alone products or services—equipment, software packages, network services.

TSMO-related IT needs are often unique within a public agency and may be a lone application of the system or services. As such, there may not be a standard process or even familiarity with the products, services, or providers. For example, data sources such as probe traffic data or weather monitoring services are readily available but may not fit in operating budgets. Many agencies that do not have enough funding in operations or maintenance budgets choose to program capital improvement funds to purchase such data. In addition, IT support may be needed for custom analytics or integration into existing systems.

The establishment or upgrade of a traffic management center is a unique hub of field data, media(e.g., video), and interagency networking that is not common for an agency to routinely build and may require a unique approach.

As an example, one State DOT identified an IT-based project that would develop a geographic information systems-based tool to assist in maintenance management. State legislation required the project to be led by the Statewide IT department because the tool would have IT components. The State DOT prepared the initial Request for Proposals based on the TSMO business needs, however the assigned IT department project manager followed standard enterprise IT contracting language. Because some of the TSMO-specific requirements were omitted from the standard procurement language, the contract took three years to complete instead of the original estimate of one year.

After completion, DOT staff identified two possible alternatives to the selected approach. First, identify if vendor-hosted services could be used to reduce internal IT burdens. Second, break the project into smaller contracts, each of which would be easier and less complex to manage.

#### *Planning-3: Business Metrics and Performance Measures for TSMO Are Not Integrated in IT Unit's Management*

Business metrics and performance measures are important aspects to track an organization's progress, identify trends, and communicate vital information to leadership. The development of business metrics and performance measures will be depend on the function of each business unit but can support the goals and objectives of the larger organization. Primary TSMO metrics typically focus on traffic operations measures, such as safety, efficiency, and reliability. Agencies often choose to have performance metrics include the IT components that TSMO relies on. For example, TSMO relies on many IT assets to monitor and operate roadway infrastructure as well as perform data analytics. These various IT-related steps need to be reliable and functioning to deliver on the primary TSMO business metrics. Performance measures surrounding field device "uptime" or reliability may be part of a TSMO operating unit but not included in an IT unit's performance measures because they do not have similar field devices in their normal IT operation. Without similar performance measures within the IT unit, the tracking of needs and support resources may not be visible to appropriate IT leadership.

### A.2.2. Procurement

This subsection discusses common challenges related to procurement. Procurement consists of the processes and procedures associated with buying IT-intensive products or services.

### *Procure-1: Statewide Procurement Policies and Procedures Often Do Not Align With TSMO Initiatives*

Procurement policies are established to provide a structure to purchase and acquire goods and services. These policies help suppliers and vendors understand the requirements and navigate the process and protect the agency against harmful actions, whether willful or unintentional. Often, these policies are developed to apply to the widest range of services or departments to minimize cost and administrative burden on the agency.

Many IT goods and services are procured through large bulk orders which allow for efficiencies through volume orders, repeat orders, or open contracts. Some TSMO-related IT needs fit well under this arrangement, such as traffic detection or closed-circuit television (CCTV) cameras, electronic signs, or radios. Other TSMO-related IT goods or services often fit in a niche market and are provided by a narrow field of competitors that may not lend themselves to large bulk procurements. Traffic signal controllers and ramp meter controllers are examples of these types of niche TSMO purchases. Working through procurement with IT staff who are unfamiliar with transportation-specific devices often leads to significant adjustments to typical IT procurement practices, adding time and expense to the effort.

### *Procure-2: Purchasing Activities Require Multiple Levels of Approval Across Groups*

A primary purpose of procurement offices is to regulate purchasing activities through policy and administration. This typically involves removing the advertising and selection process from the end user to preserve a fair and transparent award. To maintain this order, there is limited delegation of authority to individual divisions or groups.

Most agencies' TSMO-related procurement processes follow the established approval process within the procurement organization, which may include multiple levels of authorization and administration. If the contracts are atypical or of a certain magnitude, these approvals are concentrated to a select few procurement officers who have the appropriate authority. The limited capacity of these approvers, combined with requests from multiple agencies, may increase the time required to process contracts particularly if managed on a sequential basis.

As an example, the research identified one agency in which the TSMO group is required to obtain several levels of approvals for procurement, including approval from the Statewide IT agency. The various approval levels often result in a time-consuming procurement process.

### *Procure-3: Business Needs for TSMO Require Both Legacy and Emerging Systems*

The management of traffic operations has been part of many DOT programs for decades. Early efforts centered on traffic detection, video surveillance, and dynamic message signs. Many of these systems are still in operation, and agencies rely on continuing the existing IT platforms that store, analyze, and communicate the data.

As agencies transition to emerging systems for increased breadth and depth of information, the legacy systems are often still required. Procurement activities involving emerging technology may focus only on the requirements of the new system and not integrating and continuously operating the existing systems. Often the amalgamation of the various systems requires

specialized services to transfer or translation between the systems or a new software platform that utilizes both systems.

Legacy platforms utilized in TSMO systems may also be considered outdated or to pose security vulnerabilities by enterprise IT groups or centralized procurement offices. In these situations, Statewide administrators may attempt to eliminate procurement contracts if they are not regularly used or supported by larger IT efforts. While eliminating older contacts may increase efficiencies for procurement offices, it may reduce options for TSMO efforts in the future.

### *Procure-4: Lack of or Limited Pre-Approved TSMO-Related IT Equipment/Services Can Slow Efforts*

Agencies often use pre-approved product or vendor lists to reduce the time required to obtain equipment or services. These lists are developed through the early evaluation of products and services against specifications or requirements but without specific authorization for purchase. As needs arise, agency groups can utilize the pre-approved lists to acquire products or services.

Pre-approved product lists are commonplace for certain groups within DOTs that have well-defined specifications or product requirements that vendors can be evaluated against. Examples of traffic items include pavement marking paint, traffic-control cabinets, roadway luminaires, and breakaway bases, all of which are standard in design and application.

TSMO related IT products are not easily included in pre-approved lists due to the lack of design standards or specifications and the rapidly evolving requirements. The time required to develop specifications, solicit vendors, evaluate equipment, and obtain approval is often prohibitive in an environment like TSMO, where needs change and procurement activity is neither high volume nor standardized. Pre-approved products or contracts for specific equipment and devices are crucial in maintaining and replacing spare parts as devices need to be replaced.

## A.2.3. Systems and Technology

This subsection discusses common challenges related to systems and technology. Systems and technology encompass all hardware and software components of data acquisition, management, and utilization technologies.

### *Tech-1: Challenges Maintaining Legacy Systems and Deploying Emerging Technology*

Many TSMO agencies have well-documented procedures and staffing guidelines for the existing technologies on which they rely. However, these legacy systems may not be compatible with or may not complement newer technology. As agencies implement emerging technology, they may want to develop new approaches to support both legacy equipment and the new technology.

Many TSMO systems and devices are expected to last 10 to 20 years, and funding cycles to upgrade or replace these systems and devices reflect this lifecycle. As new technology is implemented—either as older legacy systems come to the end of their lifecycle or as new systems are deployed—agencies face the challenge of operating and maintaining new technologies while continuing to maintain legacy equipment and systems. Agencies have found that both maintenance and operations staff need to be proficient in both new and legacy systems.

Agencies have also found that spare parts and replacements need to be maintained for all the technologies implemented. These challenges are faced in virtually every type of TSMO system, from traffic signal, to environmental sensor stations, to dynamic message signs, to cameras and detectors.

As an example, the research identified one agency that operated several different systems that all worked individually, but not together in an integrated or interoperable way. The growth of these systems had been ad hoc and not coordinated, thereby reducing interoperability and creating a need to integrate them afterward with no clear pathway for that integration.

> The Institute of Electrical and Electronics Engineers defines interoperability as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged." (Institute of Electrical and Electronics Engineers (IEEE). IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries.)

Common types of systems that are implemented in an ad hoc manner and later integrated over time—incorporating both legacy systems and new technology—include communication systems and devices, detectors and data collection systems, and control systems for individual types of devices (like dynamic message signs and camera systems) that are later integrated in a single management system.

### *Tech-2: Insufficient Data Communication System Bandwidth and Redundancy for TSMO Services*

Communication lines are critical to IT-TSMO efforts and allow data exchange between offices, field equipment, and other agencies. These can be fiber-optic cable, wireless cellular, radio, or other modes, including older copper lines. Each mode (and path) has a maximum bandwidth that determines the capacity of the data transfer and the types and amount of data that can be transmitted.

Functionality between locations is limited by the weakest link in the communication network. If lower bandwidth communication lines are part of a network path, the data will be constrained. This is particularly important because newer technologies generate more data and require larger bandwidths than those required by legacy systems. Challenges with bandwidth have surfaced with higher definition camera systems and connected-vehicle systems that generate a significantly greater amount data than older systems did.

Reliability in communication networks depends on mode and network structure. Networks that are linear can create vulnerabilities for TSMO operation; the lack of multiple paths may restrict routing options and limit redundancy in the case of a localized transmission outage. This can cause significant disruption to operations that run 24/7, because repairs on underground lines may require extensive work. Traditional transportation professionals may not be proficient at designing communication networks and specifying network equipment that will be optimized for the range of equipment and pathways needed. IT staff may have more experience with and knowledge of communication networks that will support these needs.

### *Tech-3: Complications with Interoperability Between Agencies and Partners*

TSMO coordination across agencies can provide beneficial results to the traveling public. Integrating data, technology platforms, and communication networks can create synergies and expand functionality and range. Interoperability of data, software, and standards is possible but involves joint planning, and execution can be complicated due to the various TSMO and IT groups involved.

More often, different agencies have differing systems that are not directly compatible. Security issues (including firewall access and user credentials) often limit interactions to one-way exchanges or manual transactions. At the most basic level, even the exchange of data may require translation between differing formats and protocols.

As an example, the research identified one agency that had separate voice and data systems for the State DOT and public safety agencies, which did not allow for voice communication between field staff of the two agencies and did not allow for the electronic exchange of information, specifically for exchanging data between the public safety computer-aided dispatch system and the State DOT traffic management system. This lack of interoperability impacts the exchange of information during joint operations and impacts staffing and the ability to support multiple systems with limited resources.

### *Tech-4: Inability to Fully Utilize Third-Party Data and Crowdsourcing Data and Services*

The availability of third-party data and crowdsourcing data can improve an agency's ability to evaluate and respond to conditions. The datasets vary widely but can provide real-time, granular information across an extensive geographic area. To access the data, agencies will overcome various obstacles including but not limited to justification, funding, data management, and risk assessment.

External data sources (such as third party and crowdsourcing) often require a subscription and continued investment to receive a constant feed. Benefits of these data services are not always easy to identify and quantify against the cost, which may pose a challenge for agencies seeking to justify the additional costs.

Internal agency policies may prevent use of certain external data. For example, risk management groups may not allow the use or distribution of unverifiable data or data that is generated from unknown sources. Procurement rules may prohibit acquiring data that may be proprietary or sole-sourced.

From a technology or process standpoint, third-party data generally provides access to new information, but it is not customized. Additional effort is often needed to develop tools, automated tasks, performance measures, or other output that utilizes the third-party data for agency goals.

### *Tech-5: Emerging Technology in Connected and Autonomous Vehicles and Smart Cities Requires Significant IT Resources.*

Connected and autonomous vehicles (CAV) and Smart Cities are evolving through various pilot projects, and the scope of each is still being refined. The IT needs for these efforts are still unknown but will likely be significant. Each of the two initiatives relies heavily on technology, particularly communication and data. These are skill sets that most TSMO groups depend on IT for support.

CAV and Smart Cities initiatives are not typical applications for an agency; therefore, IT staff may not be familiar with either. IT groups may not be fully engaged in the upfront planning or scoping of emerging technologies, and technical resources may not be clearly identified. Extensive partnership between multiple agencies, private service providers, manufacturers, utilities, and other public and private organizations can further complicate identifying IT resources and who is responsible for each function.

### *Tech-6: TSMO Initiatives are Impeded Due to Lack of IT Flexibility in Enterprise Operations*

Centralized IT groups are designed to maximize efficiencies in technology infrastructure, software platforms, services, and staffing across an entire agency or across an entire State. Through deliberate planning, IT groups focus on integrating and replicating technology to simplify staffing, reduce costs, and improve internal reliability. TSMO strategies may rely on specialized IT approaches and platforms that may not coincide with other groups within an agency and may run counter to central IT objectives.

State IT policies and standards have been developed over time and may pre-date TSMO needs. The rigidity of these policies may impede TSMO efforts if central IT leadership is not receptive of the requests and does not provide resources.

As an example, the research identified one agency in which the IT department and the transportation agency had overlapping definitions of "engineering" and "data processing." Both agencies believed they were responsible for traffic management systems. The IT department viewed these systems as "data processing" systems and therefore under their oversight. The transportation agency viewed them as essential systems to deliver transportation "engineering" solutions, and therefore completely within their authority. IT oversight involved processes and technologies that did not result in traffic management systems that met the transportation agency's business needs. The lack of flexibility in the definition of "data processing" versus "engineering" led to added time and expense in the procurement and implementation process, and in procuring systems that did not meet the transportation needs as well as they could have.

### *Tech-7: Designing Complex Intelligent Transportation Systems Require a Systems Engineering Approach With Which IT Staff May Not Be Familiar*

The complexity of TSMO systems may call for a systems engineering approach to successfully deliver a reliable project. The systems engineering approach starts in the planning stage and continues through design, construction, implementation, and operation with checkpoints and reviews at each stage. The benefit of the process is to reduce risk, improve reliability, and ensure all needs are considered.

Despite the wide use of the systems engineering process, agencies may underestimate the need on TSMO projects due to a perceived "off-the-shelf" simplification of the technology. In efforts to speed programming, TSMO projects may proceed through planning and scoping without the full benefit of the process. (See 23 CFR 940.11, sets requirements regarding the systems engineering process, standards, and interoperability for ITS projects that use Federal funds.)

When used on TSMO projects, the process is typically managed internally and coordinated with other stakeholders. While most efforts include neighboring agencies, law enforcement, maintenance, operators, and other key resources, IT staff may be overlooked in the initial steps. The lack of initial input from IT at the planning and scoping stages can increase risk and scope changes later in the process.

### A.2.4. Risk/Security

This subsection discusses common challenges related to risk and security. Risk and security include those challenges associated with network security, data sharing, third-party applications, hosted and cloud platforms, and automation.

#### *Risk-1: Cybersecurity Vulnerabilities*

Public agencies face an increasing number of cyber threats as technology systems become more ubiquitous and integrated in operating physical assets. Technology-based applications that are more passive (such as surveillance or detection) are not as critical or as targeted as those that are more active and control-based. Systems that use technology to control, communicate, or operate physical assets (whether traffic signals or transit vehicles) can be high-value targets for cyber-attacks. Attacks on these systems can cause significant immediate operational and safety impacts, as well as longer-term societal impacts as trust in the systems are eroded. Longer replacement cycles for TSMO and ITS devices, compared to that for IT assets, increase cybersecurity risk, because the older devices may not have security patches available.

Vulnerabilities in cybersecurity are varied and can occur in different parts of the agency system. Traditional malware can access networks if not identified or filtered by security software or firewall, or when users fail to patch software updates. External users can also access networks through weak password control (e.g., user accounts with no password protection, common "admin" accounts, or written passwords attached to equipment).

The emergence of connected vehicles adds another attractive target for cybersecurity threats. Intrusions into connected-vehicle control systems could provide direct threats to the safety of the traveling public as well as reduce confidence in these systems and in transportation agencies that support them.

As more devices are deployed and web-based service or cloud computing is utilized, cybersecurity becomes more important as the location and type of threats multiplies. The effective network within the emerging Internet of Things becomes exponentially larger and the complexity of multiple platforms can introduce new vulnerabilities.

A relatively common example of cyber-attacks that agencies experience is "hacking" dynamic message signs. While not presenting immediate danger, rogue posting of messages can misdirect drivers, offend the public, and reduce confidence in the agency.

### *Risk-2: Lack of Robust Data Governance Rules*

Many TSMO efforts rely on data to monitor and evaluate operations. Historical data sources were often agency-owned and limited in scope to vehicle count and speed data, which were manageable in terms of size (data fields), quantity, and sensitivity (personal identifiers). Newer data sources provide significantly more information but call for a new approach to data management.

Advances in technology have created many new data sources ranging from Wi-Fi/Bluetooth sensors, license plate readers, third-party probe data, and lidar mapping. Each source has varying degrees of personally identifiable information, various formats, varying size, and other factors. The third-party data is often a combination of many data sources and often references the "four V's" of big data: volume, variety, velocity, and veracity.

Agencies have experienced challenges in managing the various data sources due to the lack of robust data governance regarding ownership, storage, sharing, and other factors. The absence of these rules creates security concerns for IT and data professionals and impacts the design of systems and platforms to analyze and archive the data.

As an example, the research identified one agency in which there was a general lack of planning—particularly in systems engineering—for data use and archiving. In this case, the issue was compounded by differing data protocols between agencies. The lack of a data management plan or a Concept of Operations for data use and archiving resulted in each headquarters or local office developing their own data standards. In fact, the data protocols could differ on a county-by-county basis. This inconsistency hampers interoperability and reduces the ability to host a common data archiving system or prepare combined analyses.

### *Risk-3: Increased Sharing of Information With a Third Party Can Increase Security Risks*

The exchange of data between DOTs and third parties has increased due to the overlapping of services and potential benefits in the sharing of information. Often, DOT-owned data can provide third-party data providers with ground truth and fill gaps in their data sources while third-party data can provide DOTs with a broader coverage than traditional field collection.

Many third-party data providers are requesting data directly from the DOT, either as a stand-alone request or as an ongoing exchange of data. Many of these requests may not identify the end use or ultimate consumer, because the data can be combined with other sources and repackaged. There are no standards regarding the business need and level of access required, because many State DOTs and third-party data providers are still evaluating the utility and value of the data. Specifics on how to deal with sensitive information, liability, and public "open access" rights are typically not available or developed on a case-by-case basis.

### *Risk-4: Location of TSMO Network has Impacts to Security, Support, and Availability*

Many aspects of TSMO have a heavy reliance on IT systems for field connectivity and software platforms. These systems and external connections, when installed on central networks, may be limited in terms of access due to strict IT administrative rules. This has led some TSMO groups to locate these systems on separate networks to maintain separation and allow more flexibility and autonomy. The level of network security, access, and IT support may differ depending on the network location.

TSMO groups with systems installed on central networks have encountered issues with being able to share data with organizations outside the agency's security firewalls, incompatible system updates, and limited system and data access without IT approval. These factors are designed to maintain consistent network security across an agency but may have unintended impacts on TSMO functions (such as limited remote access and barriers to data sharing and sharing control with partner agencies).

TSMO groups with systems installed on separate networks have more flexibility in terms of administrative rights, software updates, and access. However, IT groups may have limited knowledge of these networks, which limits the support IT groups can provide. If TSMO networks are not connected to the primary IT network, IT staff would be unable to regularly monitor the TSMO networks, and the TSMO networks may be considered external to the agency's primary network.

As an example, one TSMO group that participated in the agency outreach effort of this project had lost their ability to view some video feeds on computers tied to the agency network. The issue originated from new security policies that were implemented by the enterprise IT group, which did not allow the types of video used by the transportation agency's CCTV system. The IT staff was not aware that any agencies on the network used this type of video. As an immediate resolution, the computers were moved onto a separate network to bypass the newly created conflict.

### *Risk-5: Summarized Data Sets and Analyses Can Mask Accuracy and Reliability Issues*

The availability of third-party services, whether data or analytics, can improve TSMO operations by providing expanded datasets and/or quicker analysis. Introducing these services can reduce workload on staff and potentially automate complicated data processes. However, the lack of access to the raw data or lack of understanding of the underlying processes can mask accuracy or reliability issues.

External datasets (such as probe data) are a compilation of numerous individual datasets that are combined, assessed, and validated prior to being delivered to agencies. The processes involved are typically proprietary, and the end product is not transparent in terms of source or quality. Due to the lack of source data or validation methods, agencies generally either take the data at face value or perform limited checks against other available data.

Transportation professionals may not be aware of these issues and may not have the knowledge to incorporate ways to overcome these challenges in contract language. IT staff may be available

who would be able to support TSMO staff in proposing contract language that include accuracy and reliability measures that would be acceptable to the data vendors.

External analytics are another service that is not easily deciphered. The end product can be customized to meet the agency's goals, but the internal mechanics and processes are typically hidden within proprietary software. Some systems also include internal datasets that are not transparent. Rigorously checking the validity of the output may be beyond the capability of internal TSMO staff. However, IT staff may be available who would be able to assist TSMO staff in procurement documents or contract language to provide confidence in the analytics and an understanding of the analytical process while being acceptable to the vendor.

***Risk 6: Field Equipment is Susceptible to Physical Damages***

Many IT systems deployed by TSMO are either installed within the public rights-of-way or rely on equipment installed in the rights-of-way. Examples include fiber-optic cable, network switches, signal controllers, traffic sensors, and power sources. Each device or connection installed in the field is susceptible to physical damage, whether accidental or intentional.

Accidental damage to IT equipment can occur due to a variety of sources. Common occurrences include vehicular impacts, power surges, lightning, water, flooding, construction work, and extreme temperatures. Intentional damage is less common but has occurred due to copper theft, gun shots, vandalism, or curiosity.

TSMO staff may not be alerted to damaged field equipment unless it is reported by police, maintenance staff, or the public. Often, stand-alone equipment may not trigger an automated alert that it is inoperable, and there may be a delay in identifying the lack of utility. Damage to connected IT infrastructure may be identified more quickly because the impact may be greater than the single location. For example, broken fiber-optic cable would impact an entire network of devices and the outage would be quickly noted.

# APPENDIX B. IDENTIFIED PRACTICES

This appendix synthesizes the "lessons learned" through the project research and provides a range of current practices to deal with the common challenges described in chapter 5. The individual practices are categorized within functional groups based on common approaches. Within each group, there are general practices that can be beneficial for effective coordination as well as more specific tactics that address a narrower challenge. Where feasible, specific agency examples are provided for individual practices based on interviews and outreach efforts.

## B.1. COLLABORATION

This section discusses practices that relate to collaboration, whether informal or formal. Examples of informal collaboration include increasing the understanding of IT and TSMO objectives, clarifying roles, and integrating staff. More formal efforts relate to modifying organization structures, implementing policies, and creating intergovernmental agreements (IGAs) or Memorandums of Understanding (MOU).

### B.1.1. General Practices

#### *Improve Communication*

In many cases, issues arise because of a lack of mutual understanding between IT and TSMO groups because of little or poor communication. This occurs at all organizational levels, from senior leadership to frontline staff.

Senior managers can improve communication by encouraging IT and TSMO staff to directly engage on a routine basis by allotting time for regular group meetings. Such meetings would serve to improve mutual understanding of technologies, staff technical abilities, agency processes and work needs, scopes and deadlines and could be aligned with other annual or quarterly business process meetings.

Initial meetings could take the form of a facilitated workshop or partnering session to develop a common understanding of each group's business goals, needs, and priorities. The meetings could evolve into forming an IT advisory group that could identify and recommend solutions to a wide variety of issues that can produce benefits from both a TSMO and IT perspectives.

As an example, the Louisiana Department of Transportation and Development (DOTD) holds regularly scheduled meetings with their counterparts within the Louisiana Office of Technology Services (OTS) to discuss issues and needs related to technology systems and networks.

#### *Clarify Roles and Responsibilities*

In large agencies, it is important for the roles and responsibilities of each group or unit to be clearly defined to avoid confusion. This is particularly important as it relates to shared facilities and functions, which can be the case between TSMO and IT.

In instances where there are shared systems or facilities, it is appropriate to have documentation that delineates ownership or responsibility between the groups. By creating clear lines of

authority and clarifying roles and responsibilities, both within TSMO and IT groups and between groups, the agency can reduce confusion in obtaining service, justifications, and approvals.

In addition to clarifying the roles and responsibilities in general terms, an agency can maintain an active organization chart of key members with appropriate contact information. This data can be regularly updated and distributed to or accessible by all group members.

As an example, one TSMO group that participated in the agency outreach effort of this project works closely with their IT counterparts to understand the group's skills and develop clear and specific roles. As a result, the TSMO staff focuses on the operational technology (OT) while the IT staff focuses on security, documentation, and business processes.

### B.1.2. Specific Tactics

#### *Integrate IT Staff within TSMO*

Agency staff is typically assigned to separate and distinct departments that focus on their own missions and business processes. Creating opportunities for IT staff to work within the TSMO structure on current activities can enhance collaboration and improve their understanding of the TSMO mission as well as the end-user experience of data and software platforms.

These opportunities can range from permanent assignments to temporary rotations to routine (e.g., weekly or monthly) visits and may include onsite IT support tasks or observing TSMO operations. A very important and useful task that IT staff can perform collaboratively with TSMO staff is to analyze cybersecurity risks and recommend approaches to eliminate or mitigate vulnerabilities.

If staffing resources preclude recurring efforts, agencies can target stand-alone efforts or projects to integrate staff. This additional exposure can improve comprehension between the staffs during future project development, service requests, or other activities.

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These opportunities can be organized in various ways from permanent assignments, temporary rotations, or routine (e.g., weekly or monthly) visits, and may include onsite IT support tasks or observing TSMO operations. An IT advisory group can help integrate IT staff within a TSMO organization. A very important and useful task that IT staff can perform collaboratively with TSMO staff is to analyze cybersecurity risks and recommend approaches to eliminate or mitigate vulnerabilities. If staffing resources preclude recurring efforts, agencies can target stand-alone efforts or projects to integrate staff members. This additional exposure can improve comprehension between the staff during future project development, service requests, or other activities.

As an example, the research identified one agency that invited their IT group to the TSMO Capability Maturity Model (CMM) exercises to facilitate a wider discussion and understanding of the whole process.

### *Modify Organizational Structure*

Changes to organizational structures can be used by agencies to formalize relationships between TSMO and IT groups. Potential modifications to organizational structure to improve relations between IT and TSMO staffs can include establishing specific organizational units with responsibility to improve collaboration and coordination between IT staff and TSMO staff. The size of such groups can range in size from one person from each discipline to small groups, depending on the relationship, and can vary in location on the organization chart. The groups can either be in the IT or the TSMO organizational structure. The important aspect is that the mission of the group is to facilitate the interaction between IT and TSMO staffs.

In instances where recurring support for a specific TSMO group can be assigned to a single IT position or group, creating a relational link can clarify the role and assignment while keeping the IT resource within the IT structure. In instances where the support is more direct and consistent, agencies may elect to transfer the IT position to the TSMO organizational structure with oversight either remaining in IT or transferring to TSMO. Another option to increase collaboration between the groups when there may not be clear relationships at the staff level is to assign coordinators or liaisons who have the responsibility to coordinate the groups.

As an example, one TSMO group that participated in the agency outreach effort of this project had assigned a dedicated IT staff person to TSMO to focus on the communications network and data management. This person was embedded in the DOT rather than IT office to improve the working relationship.

### *Implement Coordination Policies*

To increase interaction between the TSMO and IT groups, agencies can develop internal policies and procedures that require mandatory “touch points” or coordination efforts through either existing or new processes. These efforts can relate to planning or scoping, project delivery, performance measures, security assessment and mitigation, or other steps that may involve both groups or would benefit from the input of both groups.

During TSMO planning efforts, reviews by IT staff or an IT advisory group can help identify technical issues or opportunities that may become significant in subsequent stages of development. If TSMO staff involvement is formalized aspect in the IT development process, this can improve the functionality and usability..

### *Develop Formal Agreement*

When TSMO and associated IT activities occur across agency boundaries or organizations, it is important to document the specific intent and scope of the effort and the roles and responsibilities of each member or owner. An MOU or an intergovernmental agreement can serve as a formal contract documenting these factors. As legal documents, the creation of these contracts typically involves review and approval by agency attorneys.

Even across internal agency divisions or offices, formal agreements may be important to have in writing. Such formal agreements may take the form of relatively simple memos or even emails or may be formalized in service-level agreements.

By establishing a formal agreement, agencies can clearly articulate the needs of the project and hold each party accountable. The range in topics covered by the agreement could be broad. Examples include:

- Formal processes and procedures for selecting procurement mechanisms.
- Specifying the points in the project development process where IT staff are included.
- Agreement on the specific roles and responsibilities for staff in each organization.
- Comment timeframe requirements for reviewing documents, by document type.

The formal agreement will ultimately serve as a reference for a larger audience and help maintain consistency through staffing changes.

## B.2. STAFFING

This section discusses practices that relate to staffing—from identifying needs to recruiting and outsourcing. Chapter 3 includes some specific examples of staffing practices that have been implemented. The discussion below includes some of these practices, generally at a summary level of detail.

### B.2.1. General Practices

#### *Establish Staffing Needs*

Introducing TSMO initiatives, particularly those with ongoing operations, can include an assessment of staffing requirements not only within the TSMO group but in external support groups as well.

To facilitate IT coordination, any technology-based TSMO effort can detail the IT resources required to develop, operate, and maintain TSMO related IT functions or systems. This effort can be based on historical efforts (if available) or projected needs and can include required staff skillsets in addition to number of staff. In response, IT organizational units can develop a staffing plan to ensure resources or a plan to obtain the skillsets both in the short-term and the long-term are available.

As systems become operational or get retired, staffing resources will change. Staffing coordination between IT and TSMO groups can be integrated into recurring business planning efforts to provide continuity.

#### *Provide Staff Training*

An agency can provide training opportunities for TSMO and IT staffs to build adequate internal resources and maintain consistency in the agency. The use of training not only increases the functional technical capability of staff members but can also provide promotional opportunities and indirectly increase retention through personal growth.

Basic levels of training can provide a baseline understanding of TSMO to both TSMO and IT staffs. Training can be an important way to provide awareness of important aspects of either TSMO or IT work and conditions (for example, the unique aspects of safety and security regarding roadside field equipment and the potential for equipment damage). This level of training can be provided through instructional materials such as webinars or online material. The National Operations Center of Excellence (NOCoE) has a helpful section on workforce development that includes a TSMO training database (Workforce Training Database). The database allows a user to search for the type(s) of training of interest and see what NOCoE has identified. The layout of the search function for the database is shown in figure 3.

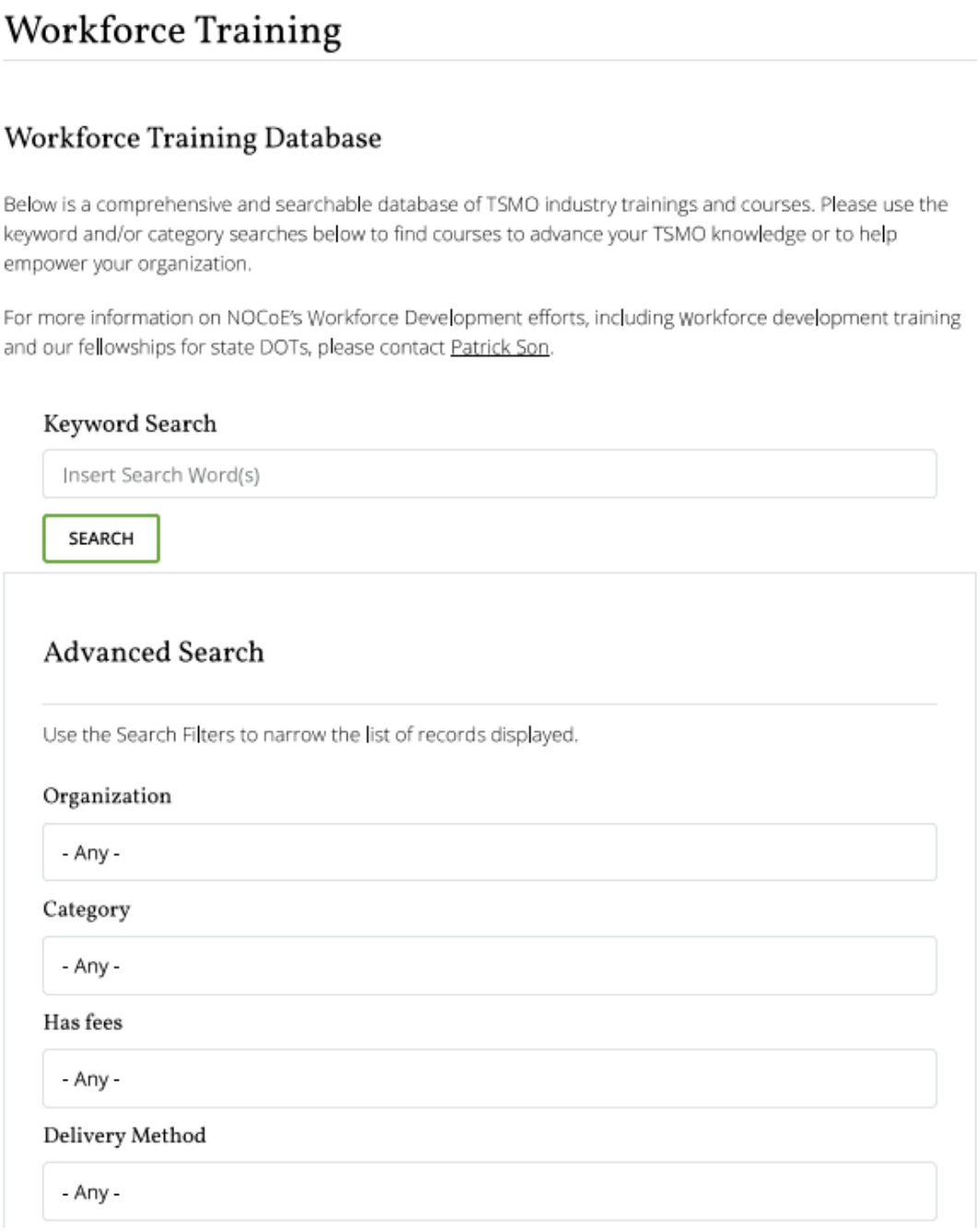


**Figure 3. Screenshot. National Operations Center of Excellence workforce training database search page.**
(Source: National Operations Center of Excellence.)

The database includes training from associations, such as the Institute of Transportation Engineers, universities, and Government organizations, such as the National Highway Institute. More advanced and specialized TSMO functions are typically unique to the organization and may call for tailored training. Preferably, these training efforts can be developed in-house and delivered with hands-on or observational elements to familiarize staff with the specific applications and processes.

As part of this training effort, agencies can formalize the necessary knowledge, skills, and abilities (KSA) needs for TSMO and IT staff and link these requirements to hiring and promotional opportunities. The allowance of automatic promotional steps based on completed training can further incentivize staff.

As an example, the TSMO group for Florida DOT developed specialized on-the-job training to respond to hiring constraints that prevented the group from hiring network specialists. The training was developed to provide transportation management centers (TMC) staff with the fundamental knowledge to work with IT networking.

### B.2.2. Specific Tactics

#### *Mix TSMO Technical and IT Staffs*

The staffing of TSMO and IT, while separate organizationally, can be integrated to deliver the required agency resources. Integrating TSMO and IT can help increase staff availability, staff knowledge, and coordination.

As TSMO and IT workloads fluctuate in magnitude and duration, the strategic borrowing of resources between the groups can help augment staffing and provide continued delivery of services. In critical situations such as equipment failures or after-hours efforts, this can result in quicker response times and less downtime.

This type of staff sharing relies on deliberate cross-training and coordination to be successful. To be effective, staff must be knowledgeable in the technical and operational aspects of each group and be familiar with the work environment. And while the specific need can be identified through a formal process to keep management apprised, some allowance of flexibility can be maintained to facilitate smaller coordination efforts.

#### *Outsource Services*

Outsourcing services, such as IT staffing, can provide agencies with the flexibility to properly staff for typical workloads while still obtaining resources when needed for specific skills, projects, or periods. Outsourced, external services can be provided in several ways, including defined project assignment or delivery, supplemental in-house staff, or as-needed on-call staffing. Outsourced services can be provided in different locations, onsite or remote. Outsourcing can be particularly attractive and effective for specialized skills, such as communication network management and cybersecurity assessment and mitigation. The procurement and contract managing of outsourced services itself involves special management skills and require advance planning.

Obtaining outsourced services involves upfront planning both in terms of procurement and financing. Agencies have reported success by identifying potential staff needs, developing requirements, and soliciting qualified sources as early as possible so that services can be obtained when needed. In addition, the funding amount of the outsourced services and the source of the funding can be identified as part of annual programming of operational or project budgets.

As an example, one TSMO group that participated in the agency outreach effort of this project outsources services in multiple ways to supplement their own staff. The group obtains support services from the technology vendors that have provided equipment through procurement contracts as well as from engineering firms that are under a retainer agreement.

### *Identify Recruiting Opportunities*

Recruitment for TSMO- and IT-related positions in the current environment involves agencies developing new techniques that widen the potential candidate pool. Recruiting can target specific audiences that may not want to work for private industry.

Public agencies can identify unique benefits and values that are available in the public sector and can attract the right long-term candidate. These can include personal benefits (such as stability, defined career paths, technical exposure, fringe benefits) or public service (such as improving safety or congestion).

Public agencies can also highlight that TSMO, and related IT positions, may not exist in other private settings. TSMO is unique in the public sector both in scope and scale, and private companies may not afford the opportunity to work on the planning, development, operations, and maintenance of the various systems.

If experienced TSMO and IT candidates are difficult to attract, establishing apprenticeship-like programs can allow agencies to hire less experienced staff and develop them from within the agency.

## B.3. PLANNING/PROGRAMMING

This section discusses practices related to planning and programming of TSMO efforts that require IT support. Practices include early coordination of plans, developing long-range needs, and allocating or maintaining adequate budgets.

### B.3.1. General Practices

### *Allocate Budgets and Resources Based on Historical Data*

To ensure IT-TSMO budget and resource needs are sufficiently and accurately met, budget requests can be based on historical cost data. Severely underestimating and overestimating budget needs both lead to eroded confidence if done repeatedly.

Separating costs by function or area can be useful in applying for different budget sources and can assist in managing the budgets during the fiscal year. For example, one funding source may support installing new devices and another may support maintaining equipment and yet another may support staffing resources. Several transportations agencies have been able to take advantage of this type of funding.

There may also be opportunities to fund IT devices (such as servers and network switches) and services used for TSMO with IT funding. When the IT group maintains and operates the communication networks used for TSMO devices, IT funds may be used for procuring new

devices, but are more often able to be used for replacing devices as they approach the end of their effective lifecycle.

Groups responsible for TSMO and IT services can accurately identify needed resources and allocate the appropriate budgets on an annual basis. Resources, both financial and other, are typically scarce if not obtained during the formal business processes.

Developing budgets using strong planning processes and historical cost data can result in more accurate projections. Underestimating and overestimating budgets can both lead to difficult situations further into fiscal years for different reasons with both eroding confidence if repeated often.

Separating costs by function or area can assist agencies in applying for different funding sources applicable to each and can assist in managing the budgets during the fiscal year. These divisions can be customized to each agency but may include the separation between installation (new) and maintenance, or equipment and staffing.

### *Establish and Maintain Systems to Manage TSMO and IT Devices and Assets*

A system that tracks and manages TSMO and related IT devices and systems will assist an agency with planning and programming by tracking and evaluating the performance of existing equipment. Such systems can provide information on the device type, brand and model, its location, purchase and installation date, purchase price and expected life, maintenance history and repair log. Many agencies include device and system tracking in their TSMO program plans.

A system that tracks and manages devices and systems—with enough time and data points—can provide better input into equipment replacement cycles, annual maintenance and replacement costs, staffing needs, and general planning efforts. Managing TSMO devices and systems in this way can assist an agency with planning and programming through tracking and evaluating existing equipment. Equipment damage is also tracked to help determine if specific locations are more susceptible to damage than others. Such information can help in the future by looking for mitigation as stand-alone actions or part of other capital projects. These systems can also be important to identify specific device replacement when damage does occur. Although developing such a system is a one-time event, the maintenance and active use of the system is critical to keep accurate records.

A system that tracks and manages devices can range from simple spreadsheets to complex software systems, depending on the appropriate level of detail. Regardless of platform, the data could include details on type of equipment, manufacturer, location, condition, last date serviced, replacement cost, and other information.

## B.3.2. Specific Tactics

### *Coordinate TSMO and Information Technology Strategic Plans*

Agencies can improve integration between TSMO and IT groups by coordinating their respective TSMO and IT Strategic Plans. Though often separate, these plans can include overlapping functions and efforts to ensure appropriate planning and programming.

Strategic plans identify high-level goals and objectives, which then form the basis for annual programming and more specific planning efforts. Because many TSMO functions require IT support and resources, including TSMO priorities in the IT strategic planning effort can align initiatives early in the process and can help identify common priorities.

Strategic plans—often created every three to five years—are not typically detailed at the project level, and therefore only set a general framework for overall direction. While early coordination of strategic plans can help increase efficiencies in the overall planning of projects and services, agencies can combine this effort with more granular programming-level coordination to better align resources.

As an example, the Connecticut DOT develops its five-year IT Plan based on internal agency customer needs. The plan begins by defining technology needs and priorities of each group (TSMO included) and then aligns business goals and initiatives with technology solutions.

### *Develop Long-Range TSMO and IT Framework*

IT-TSMO needs can be identified and formally documented in a long-range IT-TSMO framework to provide both groups a guide for future needs. This planning effort can include all existing and projected IT needs for equipment, service, and maintenance. Some examples of equipment, services, and maintenance to consider are presented in table 10.

**Table 10. Examples of information technology needs for equipment, service, and maintenance.**

| Equipment | Services | Maintenance |
|---|---|---|
| Network switches | Cybersecurity audits | Network maintenance |
| Modems | Wireless communication | IT device maintenance |
| Servers | Software development | Software maintenance |
| Monitors | Data management | Security updates |

(Source: FHWA.)

The long-range IT needs can be developed within existing TSMO strategic programming efforts or as a stand-alone effort. The development of such a document can include input from technical TSMO and IT staffs familiar with existing efforts as well as TSMO and IT leadership responsible for future efforts.

This framework can include known equipment and software needs (new or replacement), IT services or functions, and any planned or recurring maintenance efforts. Input within the framework can then be used to determine adequate internal staffing as well as funding to cover continuous operations.

### *Develop IT Policies that Support TSMO*

IT policies that are developed for a wide range of efforts (possibly established at an enterprise-level) may not support TSMO efforts and may call for modification or new rules to better respond to the unique operational environment. It is important to note that such policy changes likely require the input and approval from TSMO, IT, risk management, legal, and other teams prior to being implemented. Agencies should consider the administrative and legal frameworks

in which they operate when developing or modifying policy or regulatory approaches to support TSMO efforts.

Internal policies that can directly improve support to TSMO are those that focus on staff resources. Allowing additional staff overtime and outsourcing services can both increase the available manpower and decrease response time to cover typical 24/7 operations, as well as emergencies.

Internal policies that can improve TSMO functionality are those that focus on hardware and software systems. From a hardware perspective, allowing equipment purchases directly from a pre-approved list can reduce approval wait times. For software, allowing remote access for internal and external partners can allow quicker responses and increased sharing of information. Increasing administrative rights for TSMO staff can allow minor software updates and reduce the direct burden on IT staff.

Finally, policies can address specific practices. For example, an agency could implement a policy to require a risk management plan in the development of all projects. The risk registry can be passed on to operations staff after the project is implemented, ensuring that the staff tracks risks and identifies mitigations throughout the lifecycle.

## B.4. PROGRAM DELIVERY

This section discusses practices that relate to program delivery and incorporating IT in the project development cycle. The goal of these practices relates to ensuring active IT involvement with project planning, technical reviews, and procurement. Each of the practices listed below represent a separate description and discussion.

### B.4.1. General Practices

#### *Involve IT Personnel in Project Delivery Teams*

Many agencies have created TSMO project delivery team to guide the development of projects and provide technical reviews at various stages. Project delivery teams also serve to speed or streamline the project delivery process because many of the primary groups who have a say in the project are represented on the team.

TSMO project delivery teams have comprised a wide range of subject matter experts, typically covering traffic operations, traffic safety, intelligent transportation systems (ITS), and traffic incident management and others. However, because IT has been traditionally regarded as an agency service organization unit rather than integral to project delivery, IT staff has not always been included on TSMO project delivery teams.

Involvement of IT staff can help ensure that State or agency policies relating to hardware, networking, and data management are followed. It will also serve to build and cement relationships between IT and TSMO staffs based by providing an opportunity to learn more about each other’s needs and work processes.

### *Develop Lifecycle Cost Model*

Projects involving technology or continued operations can include a typical lifecycle cost model to ensure adequate resources after the initial implementation. TSMO projects typically call for long-term operations staffing, equipment costs, and maintenance activities that need to be accounted for and programmed. Operations staffing include transportation management services staff, data analysts, TSMO or ITS engineers, and any other positions that directly support operations. Equipment costs include field devices (such as cameras and driver monitoring systems), network devices (such as switches and routers), and TMC or office equipment (such as servers, operator workstations, and video monitors or walls).

Evaluating lifecycle costs for future financial and staffing requirements often are prepared as early as possible in the project development timeline. Input from TSMO and IT groups can be based on historical data for staffing effort, equipment costs, maintenance cycles, and effective lifespan of hardware and software. Localized data can provide more accurate estimates particularly if resources are not accessible.

Individual project lifecycle costs are important inputs to TSMO and IT budgeting efforts. Future project resources and costs can be incorporated into annual operating costs for the respective owner and be coordinated with any comprehensive system maintenance efforts.

As an example, one TSMO group that participated in the agency outreach effort of this project incorporated device lifecycles in their business planning efforts. With input from their IT counterparts, replacement timeframes and associated costs were included in the budgeting process.

## B.4.2. Specific Tactics

### *Incorporate IT Staff in Systems Engineering Process*

TSMO projects requiring a systems engineering approach in accordance with 23 CFR 940.11 can include IT partners early and throughout the process to reduce risk and speed the process. The systems engineering approach—developed to provide multiple checkpoints during project development—can ensure interdisciplinary coordination when properly utilized.

The systems engineering approach breaks down the project delivery flow into a series of steps from planning, development, and implementation with each step referencing back to a prior step to ensure continuity. Including IT partners early in the process can help establish system requirements that will be carried through to subsequent steps.

While the systems engineering process does involve the design of hardware and software systems, it also involves systems integration, testing, and verification, which rely heavily on IT staff. IT partners also add value to the process through expertise in operations, maintenance, and eventual equipment upgrades, replacements, or retirement.

### *Establish TSMO "Approved Product List"*

The development of an approved products list that complies with the jurisdiction's procurement laws and regulations for recurring IT purchases can reduce the procurement timeframe for common IT-TSMO equipment. Many products utilized by TSMO and IT are used repetitively either in new installations or replacement activities. These products can be evaluated and pre-approved prior to their use to reduce acquisition time. Many IT offices have contracts with vendors for specific products and these contracts serve much the same function as approved product lists. However, if specific IT-related products do not fall under an IT procurement contract, working with IT staff to develop an approved products list can be very helpful.

In many agencies, creating an approved product list may implicate procurement rules and include specific guidelines for the process to maintain transparency. To place a product on the approved list, agencies can identify a need and develop standard specifications and criteria against which the product will be evaluated. Vendors would submit applications for consideration along with appropriate evaluations and testing to ensure compliance. Agencies should consider the administrative and legal frameworks in which they operate when developing or modifying policies and procedures to support TSMO efforts.

Prequalifying products can help reduce delivery time by eliminating or reducing the time required for research, evaluation, and approval. This can be particularly beneficial for TSMO or IT products that have longer lead times or projects with shorter schedules.

### *Adjust Procurement Process for Transportation Systems Management and Operations*

Procurement rules and processes are varied, and agencies can identify the best approach for TSMO and IT efforts, given the required type of equipment, service, or timeframe. Selecting the most appropriate method for TSMO and IT may be different than methods for other transportation activities.

TSMO and IT efforts that use external services or products on a continual basis or during emergencies can be supported through open-ended or annual procurements that allow flexible use of contracted staff. An example is the use of on-call or staff extension contracts. Florida Department of Transportation (FDOT) District 6 utilizes both contracting mechanisms. TMC operations are contracted as a staff extension contract that details the staff required. FDOT can then assign activities as needed. Through their on-call contracts, they can issue task orders to the contractor for specific tasks, as well. Under both mechanisms, FDOT District 6 can assign some IT-related activities to contractor staff. This approach reduces the time required for solicitation and approval of contracts for specific tasks.

For smaller purchases, procurement rules may allow direct purchases under a certain dollar amount. This method can facilitate acquiring smaller IT products that may be needed for maintenance or replacement.

For complex technology projects, specific project-level procurement plans may be developed with procurement personnel. In some arrangements, hardware and software platforms may require long-term commitments or proprietary products in the future.

As an example, the Pennsylvania Turnpike has the flexibility to use the most appropriate contracting approach available. The agency can utilize Statewide contracts or develop their own procurement.

### *Establish TSMO and IT Project Review*

Agencies can require that all projects involving technology be reviewed and approved by TSMO and IT staff. In most cases, the operations and maintenance of these systems will be performed by TSMO or IT; therefore, the project development process could benefit from a formal review by applicable staff.

For complex technology projects, a systems engineering approach can be beneficial and could include reviews by TSMO and IT participants. For smaller projects, an abbreviated review may be appropriate but may still comprise the same participants. These processes can include documented approvals by those staff assigned review authority within their respective groups or units. In any case, all ITS projects using Federal funds must undergo a systems engineering analysis, as required by 23 CFR 940.11, although the complexity of the analysis will depend on the scope and complexity of the project.

To maintain consistency and ensure completeness, a defined step-by-step review process or checklist may be developed to guide the reviews. An example of a TSMO project development checklist can be found in the Texas DOT Austin District TSMO Program Plan. Although this checklist does not specifically show touchpoints with IT staff, it does include the full project development process, and specific touchpoints with IT staff could be easily identified. For example, under preparing a cost estimate, if IT equipment is included in the project, consulting IT staff at this point would be appropriate.

If separate checklists are developed for the TSMO and IT groups, the checklists can be coordinated so each group is aware of the other and critical topics are not omitted.

## B.5. EQUIPMENT/SYSTEMS

This section discusses practices that relate to technical equipment and systems required to support TSMO functions. The practices identified are wide ranging, from establishing security systems and improving communication infrastructure to data sharing and data management.

### B.5.1. General Practices

### *Maintain an ITS Architecture*

An up-to-date ITS architecture can be maintained to facilitate the development and management of technology infrastructure. (According to 23 CFR 940.9, regions are required to develop and maintain regional ITS architectures.) In addition to TSMO staff, the involvement of IT staff in ITS architecture activities can increase mutual understanding of the system requirements, data needs, communication, and security.

ITS architectures provide a high-level framework that illustrates how existing and planned ITS elements interconnect and interface to exchange information and collectively deliver

transportation services and functions. The development of the ITS architecture must include all agencies that have a role in the various systems to ensure consensus among the owners and users. Within each agency, IT staff involved in data management and communication infrastructure may be included in the ITS architecture mapping efforts.

The goal of the final ITS architecture is to be easily understood by all stakeholders and readily accessible. Periodic reviews and updates may be needed to keep the architecture relevant with new services and emerging technologies.

As an example, one TSMO group that participated in the agency outreach effort of this project has developed an ITS architecture with the help of their IT group. The TSMO group invited their IT senior managers to attend the statewide ITS architecture stakeholder workshop and the TSMO and connected and autonomous vehicle strategic planning workshops to actively participate in developing and documenting the ITS architecture.

#### *Improve Data Communications Infrastructure*

Data communications infrastructure can be improved to provide adequate data bandwidth and infrastructure redundancy. Because much of the functionality of technology systems relies on data transmission, the health of the data communications infrastructure is critical to reliable operations.

Newer technology systems provide increased surveillance, data, and analysis but generate and use significantly more data both in terms of volume and velocity. The underlying communications infrastructure can be evaluated against the potential data needs and strengthened to provide adequate transmission capacity. In addition to capacity, the network can provide redundancy to ensure system reliability. Redundancy can be provided through additional or alternate paths to protect against temporary failures caused by breakage, power issues, network congestion, or equipment failure.

The network evaluation and improvement can extend beyond a single agency. Options for infrastructure sharing with adjacent agencies, public-private partnerships, and lease lines can improve network reliability at a reduced or shared cost. For example, agencies in Maricopa County, Arizona, developed a regional fiber-optic network to facilitate integrating ITS across the entire Phoenix metropolitan area.

### B.5.2. Specific Tactics

#### *Develop an Integrated Security System with IT*

Agency TSMO groups can develop an information security system for all technology systems and integrate the system with IT resources. The information security system can be part of an overall risk management program and include both physical and electronic risks to the TSMO functions.

Creating a security system can include a risk assessment prepared with IT staff that identifies potential threats and vulnerabilities, their associated probability, and potential impact. For each vulnerability, TSMO and IT staff can identify whether the risk can be avoided, accepted, or

mitigated. All avoidance and mitigation measures can be formalized through security protocols, documentation, and training.

An integrated security system may require modification from traditional or enterprise IT security requirements. TSMO and IT staff can evaluate the implications of the various system configurations and determine the impact to functionality, security, staffing, and convenience.

### *Establish Necessary Decision Support Systems*

Including decision support systems (DSS) within TSMO functions can improve response timeliness, accuracy, and consistency. The decision support systems provide analytical tools that utilize available data to reach an operational decision that supports the TSMO objectives.

DSS can have a wide range of functionality from automated real-time systems to off-line manual systems. DSS methodology follows a decision tree based on available data and evaluation criteria. Including IT resources during the development of DSS can increase data mining, analysis, visualization, and automation. Automating any processes may require increased IT support due to software requirements.

While not all TSMO functions use a DSS, they can be developed for many operational functions, including ramp metering, dynamic message signs, variable speed limits, or other dynamic features. The DSS provide staff with direct guidance while ensuring consistent application.

Developing DSS for TSMO-IT features or operations can also assist in clarifying other key system elements such as data management and security.

### *Define and Coordinate Data Sharing and Access Agreements*

TSMO functions that include outside partners, either for data or access, can formalize the arrangements though written agreements.

Technology systems often include data sharing across platforms to increase the variety and veracity of the data available. Data may be obtained from external sources such as partner agencies or third-party vendors, exported to these parties, or provided through a mutual exchange of data. This data may supplement existing data to increase the accuracy or may fill a data gap. Associated data-sharing agreements between the parties can clarify the data source, data type or format, delivery method, and appropriate security and sharing restrictions.

Shared access within a technology platform can increase the functionality of the system by allowing wider use, more timely operation, or other factors. External agencies may access a platform to observe operations, control the system, extract data, or other purposes. Shared access can be mutually agreed to and associated access agreements between the parties can clarify access rights, restrictions, and security protocols.

As an example, Maricopa County, Arizona, operates a shared data-archive network with their neighboring agencies. The shared communication network, computer servers, and data management and archiving is managed jointly and documented through formal agreements

(AZTech Regional Archive Data Server Agreement referenced in the Arizona Statewide ITS Architecture Appendix O Agreements).

### *Create a Data Governance and Management Plan*

Technology systems generate a significant amount of data that may create a challenge for agencies to manage and control. Accordingly, agencies can develop a data governance and management plan to ensure appropriate data access, ownership, integrity, quality, and control. According to DAMA International, "data governance is the exercise of authority and control (planning, monitoring, and enforcement) over the management of data assets." Data governance includes methods, technologies, and behaviors around the proper management of data to address the following: security and privacy, integrity, usability, integration, compliance, availability, roles and responsibilities, and overall management of the internal and external data flows within an organization. A data management plan also identifies how data is collected, organized, stored, and archived. Formally documenting the data management efforts can help TSMO and IT staffs operate more efficiently and assist during staff turnover. Because much of this requires database management, it is important that IT resources are involved early in the process to determine appropriate data formats, storage location, and security protocol.

A comprehensive data management plan can include all data sources—internal and external. Any system requirements relative to data file types, naming conventions, and data formats can be identified and evaluated for consistency. The plan can include procedures on data processing and analysis with a focus on maintaining version control and preserving raw data separate from processed data.

Policies and procedures can be developed on data storage—frequency, location—based on system requirements and agency archiving policies. IT staff can be involved in evaluating onsite or off-site data storage because the location can affect resource needs (hardware, staff, fees), access, and security. Data storage, regardless of location, can incorporate steps for quality control and security.

As an example, the research identified one agency that developed an advanced data management and warehousing platform that brings together data from multiple sources into a single platform for improved archiving and evaluation.

# APPENDIX C. APPLICABILITY OF IDENTIFIED PRACTICES

This appendix provides a consolidated challenge matrix with the same information as the tables found in chapter 3. It also presents a reference matrix that is the companion of the challenge matrix. This matrix allows practitioners to identify the range of challenges that each practice can address.

## C.1. CHALLENGE MATRIX

Table 11 provides a consolidated table with all the challenges and practices presented in this document. For familiar users, this may be a more convenient way to identify practices that address the identified challenges.

**Table 11. TSMO and IT practices.**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| **Culture:** Lack of mutual understanding between TSMO staff and IT staff. | Culture-1 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| **Culture:** Lack of IT staff availability when TSMO staff need IT support. | Culture-2 | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop memorandum of understanding or intergovernmental agreement. | B.1.2 |
| | | Mix TSMO staff and IT staff. | B.2.2 |
| | | Outsource services. | B.2.2 |
| **Culture:** Different staff backgrounds and roles leads to silos. | Culture-3 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| **Culture:** Shared resources and references for TSMO related IT needs are scarce. | Culture-4 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop Formal Agreement. | B.1.2 |
| | | Mix TSMO staff and IT staff. | B.2.2 |
| | | Identify recruiting opportunities. | B.2.2 |
| **Resources:** Funding sources for TSMO-IT projects are not well established. | Resource-1 | Coordinate TSMO and IT Strategic Plans. | B.3.2 |
| | | Develop long-range TSMO-IT framework. | B.3.2 |
| **Resources:** Recruiting and retaining IT staff is difficult with competition from private sector. | Resource-2 | Outsource services. | B.2.2 |

**Table 11. TSMO and IT practices (continuation).**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| **Resources:** Training requirements and programs for TSMO and IT are not provided internally. | Resource-3 | Integrate IT staff within TSMO unit. | B.1.2 |
| **Resources:** Use of private firms to provide services requires funding, oversight, and political approval. | Resource-4 | Outsource services. | B.2.2 |
| **Organization:** TSMO is limited in its direct interaction with IT leadership given the hierarchical structure. | Org-1 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| **Organization:** There is a lack of clarity in defining the roles of Department of Transportation (DOT) IT staff versus enterprise IT staff and associated IT ownership. | Org-2 | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| **Organization:** IT capability varies across the State and is often weaker in rural areas. | Org-3 | Integrate IT staff within TSMO. | B.1.2 |
| | | Modify organizational structure. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop Formal Agreement. | B.1.2 |
| | | Mix TSMO and IT staffs. | B.2.2 |
| | | Outsource services. | B.2.2 |
| **Organization:** Approval processes are challenging for the unique environment and function of TSMO. | Org-4 | Implement coordination policies. | B.1.2 |
| | | Form TSMO "approved product list." | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| **Organization:** Meeting expectations and needs can be challenging when operating key business (IT) resources is the responsibility of a separate organizational unit. | Org-5 | Integrate IT staff within TSMO. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Develop Formal Agreement. | B.1.2 |
| | | Mix TSMO and IT staffs. | B.2.2 |
| **Policy**: TSMO design, procurement or operations are affected by legislation. | Policy-1 | Implement coordination policies. | B.1.2 |
| | | Develop Formal Agreement. | B.1.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |

**Table 11. TSMO and IT practices (continuation).**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| **Policy**: TSMO procurement processes can be affected by jurisdiction level IT procurement rules. | Policy-2 | Develop IT policies that support TSMO. | B.3.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| **Planning**: Strategic planning and governing mission, vision, and goals can differ between TSMO and IT. | Planning-1 | Coordinate TSMO and IT Strategic Plans. | B.3.2 |
| | | Develop long-range TSMO-IT framework. | B.3.2 |
| **Planning**: Programming and development of TSMO related IT projects do not align with traditional construction or IT. | Planning-2 | Develop IT policies that support TSMO. | B.3.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| **Planning**: Business metrics and performance measures for TSMO are not integrated in IT unit's management. | Planning-3 | Develop IT policies that support TSMO. | B.3.2 |
| **Procurement**: Statewide procurement policies and procedures do not align with TSMO initiatives. | Procure-1 | Form TSMO "approved product list." | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| **Procurement**: Purchasing activities require multiple levels of approval across groups. | Procure-2 | Develop Formal Agreement. | B.4.2 |
| | | Develop IT policies that support TSMO. | B.4.2 |
| | | Form TSMO "approved product list." | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| **Procurement**: Business needs for TSMO require both legacy and emerging systems. | Procure-3 | Develop long-range TSMO-IT framework. | B.4.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| **Procurement**: Lack of pre-approved TSMO-IT equipment/services can slow efforts. | Procure-4 | Form TSMO "approved product list." | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| **Technology:** Challenges maintaining legacy systems and deploying emerging technology. | Tech-1 | Develop long-range TSMO-IT framework. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish TSMO-IT project review. | B.4.2 |
| | | Establish necessary decisions support systems. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |

**Table 11. TSMO and IT practices (continuation).**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| **Technology:** Insufficient communication system bandwidth and redundancy for TSMO services. | Tech-2 | Develop long-range TSMO-IT framework. | B.3.2 |
| | | Establish TSMO-IT project review. | B.4.2 |
| | | Create a data governance and management plan. | B.5.2 |
| **Technology:** Complications with interoperability between agencies and partners. | Tech-3 | Develop Formal Agreement. | B.1.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish TSMO-IT project review. | B.4.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| **Technology:** Inability to fully utilize third-party data and crowdsourcing data and services. | Tech-4 | Develop long-range TSMO-IT framework. | B.3.2 |
| | | Develop IT policies that support TSMO. | B.3.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| **Technology:** Emerging technology in connected and autonomous vehicle (CAV) and Smart Cities requires significant IT resources. | Tech-5 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Develop IT policies that support TSMO. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Adjust procurement process for TSMO. | B.4.2 |
| | | Establish IT-TSMO project review. | B.4.2 |
| | | Create a data governance and management plan. | B.5.2 |
| **Technology:** TSMO initiatives are impeded due to lack of IT flexibility in enterprise operations. | Tech-6 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Develop IT policies that support TSMO. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish TSMO-IT project review. | B.4.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| **Technology:** Designing complex ITS requires a systems engineering approach with which IT staff may not be familiar. | Tech-7 | Integrate IT staff within TSMO unit. | B.1.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Establish TSMO-IT project review. | B.4.2 |

**Table 11. TSMO and IT practices (continuation).**

| Challenge Description | ID | Practice Description | Section # |
|---|---|---|---|
| **Risk:** Cybersecurity vulnerabilities. | Risk-1 | Integrate IT staff within the TSMO. | B.1.2 |
| | | Implement coordination policies. | B.1.2 |
| | | Outsource services. | B.2.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| **Risk:** Lack of robust data governance rules. | Risk-2 | Develop Formal Agreement. | B.1.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| **Risk:** Increased sharing of information with third party can increase security risks. | Risk-3 | Develop Formal Agreement. | B.1.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| | | Define and coordinate data sharing and access agreements. | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| **Risk:** Location of TSMO network has impacts to security, support, and availability. | Risk-4 | Develop IT policies that support TSMO. | B.3.2 |
| | | Incorporate IT staff in systems engineering process. | B.4.2 |
| | | Develop an integrated security system with IT staff. | B.5.2 |
| **Risk:** Automated data sets and analyses can mask reliability issues. | Risk-5 | Mix TSMO staff and IT staff. | B.2.2 |
| | | Establish necessary decisions support systems | B.5.2 |
| | | Create a data governance and management plan. | B.5.2 |
| **Risk:** Field equipment is susceptible to physical damages. | Risk 6 | Form TSMO “approved product list.” | B.4.2 |

In addition to the specific practices presented in the challenge matrix, there are a set of 10 general practices that can also be applied to multiple challenges. The general practices that can be applied to each of the challenge categories are presented below.

***General Practices Beneficial to Cultural Challenges:***

- Improve Communication.
- Clarify Roles and Responsibilities.
- Establish Staffing Needs.

***General Practices Beneficial to Staff and Financial Challenges:***

- Clarify Roles and Responsibilities.
- Establish Staffing Needs.
- Provide Staff Training.
- Allocate Budgets and Resources Based on Historical Data.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Develop Lifecycle Cost Model.

***General Practices Beneficial to Organizational Structure Challenges:***

- Clarify Roles and Responsibilities.
- Establish Staffing Needs.
- Allocate Budgets and Resources Based on Historical Data.

***General Practices Beneficial to Strategic Planning Challenges:***

- Allocate Budgets and Resources Based on Historical Data.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Involve IT Personnel in Project Delivery Teams.

***General Practices Beneficial to Procurement Challenges:***

- Improve Communication.
- Clarify Roles and Responsibilities.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Develop Lifecycle Cost Model.

***General Practices Beneficial to Systems and Technology Challenges:***

- Improve Communication.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Involve IT Personnel in Project Delivery Teams.
- Maintain an ITS Architecture.
- Improve Data Communications Infrastructure.

***General Practices Beneficial to Risk and Security Challenges:***

- Improve Communication.
- Establish and Maintain Systems to Manage TSMO and IT Devices and Assets.
- Involve IT Personnel in Project Delivery Teams.
- Improve Data Communications Infrastructure.

## C.2. IDENTIFIED PRACTICE APPLICATION MATRIX

The following matrix presents the full set of practices described in chapter 6 and the associated challenges that each can address. In the matrix, the section number refers to where the description of the practice can be found in this report. The ID refers to the identification assigned to each challenge. A description of the challenges can be found in chapter 5.

**Table 12. TSMO and information technology practices and the challenges they address.**

| Category | Practice Description | Section # | Challenge Description | ID |
|---|---|---|---|---|
| **Collaboration** | Integrate information technology (IT) (staff) within Transportation Systems Management and Operations (TSMO) unit | B.1.2 | There may be a lack of mutual understanding between TSMO staff and IT staff. | Culture-1 |
| | | | Different staff backgrounds and roles leads to silos. | Culture-3 |
| | | | Shared resources and references for TSMO related IT needs are scarce. | Culture-4 |
| | | | Training requirements and programs for TSMO and IT are not provided internally. | Resource-3 |
| | | | Organizational structure varies across the State and is often weaker in rural areas. | Org-3 |
| | | | Meeting expectations and needs can be challenging when operating key business (IT) resources is the responsibility of a separate agency. | Org-5 |
| | | | Emerging technology in connected and autonomous vehicle (CAV) and Smart Cities requires significant IT resources. | Tech-5 |
| | | | TSMO initiatives are impeded due to lack of IT flexibility in enterprise operations. | Tech-6 |
| | | | Designing complex intelligent transportation systems requires a systems engineering approach with which IT staff may not be familiar. | Tech-7 |
| | | | Cybersecurity vulnerabilities | Risk-1 |
| | Modify organizational structure | B.1.2 | There may be a lack of mutual understanding between TSMO staff and IT staff. | Culture-1 |
| | | | TSMO's IT needs are not always project-based but require 24/7 availability. | Culture-2 |
| | | | Different staff backgrounds and roles leads to silos. | Culture-3 |
| | | | Shared resources and references for TSMO-IT needs are scarce. | Culture-4 |
| | | | TSMO is limited in its direct interaction with IT leadership given the hierarchical structure. | Org-1 |
| | | | There is a lack of clarity in defining the roles of department of transportation (DOT) IT staff versus enterprise IT staff and associated IT ownership. | Org-2 |
| | | | Organizational structure varies across the State and is often weaker in rural areas. | Org-3 |

**Table 12. TSMO and information technology practices and the challenges they address. (continuation)**

| Category | Practice Description | Section # | Challenge Description | ID |
|---|---|---|---|---|
| **Collaboration** | Implement coordination policies | B.1.2 | There may be a lack of mutual understanding between TSMO staff and IT staff. | Culture-1 |
| | | | TSMO's IT needs are not always project-based but require 24/7 availability. | Culture-2 |
| | | | Different staff backgrounds and roles leads to silos. | Culture-3 |
| | | | Shared resources and references for TSMO-IT needs are scarce. | Culture-4 |
| | | | There is a lack of clarity in defining the roles of DOT IT staff versus enterprise IT staff and associated IT ownership. | Org-2 |
| | | | Organizational structure varies across the State and is often weaker in rural areas. | Org-3 |
| | | | Approval process is challenging for the unique environment and function of TSMO. | Org-4 |
| | | | Meeting expectations and needs can be challenging when operating key business (IT) resources is the responsibility of a separate agency. | Org-5 |
| | | | TSMO design, procurement or operations are affected by policy | Policy-1 |
| | | | Cybersecurity vulnerabilities | Risk-1 |
| | Develop a memorandum of understanding or intergovernmental agreement | B.1.2 | TSMO's IT needs are not always project-based but require 24/7 availability. | Culture-2 |
| | | | Shared resources and references for TSMO related IT needs are scarce. | Culture-4 |
| | | | Organizational structure varies across the State and is often weaker in rural areas. | Org-3 |
| | | | Meeting expectations and needs can be challenging when operating key business (IT) resources is the responsibility of a separate agency. | Org-5 |
| | | | TSMO design, procurement or operations are affected by policy | Policy-1 |
| | | | Purchasing activities require multiple levels of approval across groups. | Procure-2 |
| | | | Complications with interoperability between agencies and partners. | Tech-3 |
| | | | Lack of robust data governance rules and scope. | Risk-2 |
| | | | Increased sharing of information with third party can increase security risks. | Risk-3 |

**Table 12. TSMO and information technology practices and the challenges they address. (continuation)**

| Category | Practice Description | Section # | Challenge Description | ID |
|---|---|---|---|---|
| **Staffing** | Mix TSMO staff and IT staff | B.2.2 | TSMO's IT needs are not always project-based but require 24/7 availability. | Culture-2 |
| | | | Shared resources and references for TSMO-IT needs are scarce. | Culture-4 |
| | | | Organizational structure varies across the State and is often weaker in rural areas. | Org-3 |
| | | | Meeting expectations and needs can be challenging when operating key business (IT) resources is the responsibility of a separate agency. | Org-5 |
| | | | Automated data sets and analyses can mask reliability issues. | Risk-5 |
| | Outsource services | B.2.2 | TSMO's IT needs are not always project-based but require 24/7 availability. | Culture-2 |
| | | | Recruiting and retaining IT staff is difficult with competition from private sector. | Resource-2 |
| | | | Use of private firms to provide services requires funding, oversight, and political approval. | Resource-4 |
| | | | Organizational structure varies across the State is and often weaker in rural areas. | Org-3 |
| | | | Differing approaches for use of external services. | Procure-5 |
| | | | Cybersecurity vulnerabilities | Risk-2 |
| | Identify recruiting opportunities | B.2.2 | Recruiting and retaining IT staff is difficult with competition from private sector. | Resource-2 |
| **Planning/ Programming** | Coordinate TSMO and IT Strategic Plans | B.3.2 | Funding sources for TSMO related IT projects are not well established. | Resource-1 |
| | | | Strategic planning and governing mission, vision, and goals can differ between TSMO and IT. | Planning-1 |
| | Develop long-range IT-TSMO framework | B.3.2 | Funding sources for TSMO-IT projects are not well established. | Resource-1 |
| | | | Strategic planning and governing mission, vision, and goals can differ between TSMO and IT. | Planning-1 |
| | | | Business needs for TSMO require both legacy and emerging systems. | Procure-3 |
| | | | Challenges maintaining legacy systems and deploying emerging technology. | Tech-1 |
| | | | Insufficient communication system bandwidth and redundancy for TSMO services. | Tech-2 |
| | | | Inability to fully utilize third-party data and crowdsourcing data and services. | Tech-4 |

**Table 12. TSMO and information technology practices and the challenges they address. (continuation)**

| Category | Practice Description | Section # | Challenge Description | ID |
|---|---|---|---|---|
| **Planning/ Programming** | Develop IT policies that support TSMO | B.3.2 | TSMO procurement processes can be affected by jurisdiction level IT procurement rules. | Policy-2 |
| | | | Programming and development of TSMO-IT projects does not align with traditional construction or IT. | Planning-2 |
| | | | Business metrics and performance measures for TSMO are not integrated in IT unit's management. | Planning-3 |
| | | | Purchasing activities require multiple levels of approval across groups. | Procure-2 |
| | | | Differing approaches for use of external services. | Procure-5 |
| | | | Inability to fully utilize third-party data and crowdsourcing data and services. | Tech-6 |
| | | | Emerging technology in CAV and Smart Cities requires significant IT resources. | Tech-5 |
| | | | TSMO initiatives are impeded due to lack of IT flexibility in enterprise operations. | Tech-6 |
| | | | Location of TSMO network has impacts to security, support, and availability. | Risk-4 |
| **Program Delivery** | Incorporate IT staff in systems engineering process | B.4.2 | Business needs for TSMO require both legacy and emerging systems. | Procure-3 |
| | | | Location of TSMO network has impacts to security, support, and availability. | Risk-3 |
| | | | Challenges maintaining legacy systems and deploying emerging technology. | Tech-1 |
| | | | Complications with interoperability between agencies and partners. | Tech-3 |
| | | | Emerging technology in CAV and Smart Cities requires significant IT resources. | Tech-5 |
| | | | TSMO initiatives are impeded due to lack of IT flexibility in enterprise operations. | Tech-6 |
| | | | Designing complex ITS requires a systems engineering approach with which IT staff may not be familiar. | Tech-7 |
| | | | Location of TSMO network has impacts to security, support, and availability. | Risk-4 |
| | Form TSMO "approved product list" | B.4.2 | Approval process is challenging for the unique environment and function of TSMO. | Org-4 |
| | | | Statewide procurement policies and procedures do not align with TSMO initiatives. | Procure-1 |
| | | | Purchasing activities require multiple levels of approval across groups. | Procure-2 |
| | | | Lack of pre-approved TSMO-IT equipment/services can slow efforts. | Procure-4 |
| | | | Field equipment is susceptible to physical damages | Risk 6 |

**Table 12. TSMO and information technology practices and the challenges they address. (continuation)**

| Category | Practice Description | Section # | Challenge Description | ID |
|---|---|---|---|---|
| **Program Delivery** | Adjust procurement process for TSMO | B.4.2 | Approval process is challenging for the unique environment and function of TSMO. | Org-4 |
| | | | TSMO design, procurement or operations are affected by policy. | Policy-1 |
| | | | TSMO procurement processes can be affected by jurisdiction level IT procurement rules | Policy-2 |
| | | | Programming and development of TSMO-IT projects does not align with traditional construction or IT. | Planning-2 |
| | | | Statewide procurement policies and procedures do not align with TSMO initiatives. | Procure-1 |
| | | | Purchasing activities require multiple levels of approval across groups. | Procure-2 |
| | | | Lack of pre-approved TSMO-IT equipment/services can slow efforts. | Procure-4 |
| | | | Differing approaches for use of external services. | Procure-5 |
| | | | Emerging technology in CAV and Smart Cities requires significant IT resources. | Tech-5 |
| | Establish IT-TSMO project review | B.4.2 | Programming and development of TSMO-IT projects does not align with traditional construction or IT. | Planning-2 |
| | | | Challenges maintaining legacy systems and deploying emerging technology. | Tech-1 |
| | | | Insufficient communication system bandwidth and redundancy for TSMO services. | Tech-2 |
| | | | Complications with interoperability between agencies and partners. | Tech-3 |
| | | | Emerging technology in CAV and Smart Cities requires significant IT resources. | Tech-5 |
| | | | TSMO initiatives are impeded due to lack of IT flexibility in enterprise operations. | Tech-6 |
| | | | Designing complex ITS requires a systems engineering approach with which IT staff may not be familiar. | Tech-7 |
| **Equipment/ Systems** | Develop an integrated security system with IT staff | B.5.2 | Complications with interoperability between agencies and partners. | Tech-3 |
| | | | Inability to fully utilize third-party data and crowdsourcing data and services. | Tech-4 |
| | | | TSMO initiatives are impeded due to lack of IT flexibility in enterprise operations. | Tech-6 |
| | | | Cybersecurity vulnerabilities. | Risk-1 |
| | | | Increased sharing of information with third party can increase security risks. | Risk-3 |
| | | | Location of TSMO network has impacts to security, support, and availability. | Risk-4 |

**Table 12. TSMO and information technology practices and the challenges they address. (continuation)**

| Category | Practice Description | Section # | Challenge Description | ID |
|---|---|---|---|---|
| **Equipment/ Systems** | Establish necessary decision support systems | B.5.2 | Challenges maintaining legacy systems and deploying emerging technology. | Tech-1 |
| | | | Automated data sets and analyses can mask reliability issues. | Risk-5 |
| | Define and coordinate data sharing and access agreements | B.5.2 | Complications with interoperability between agencies and partners. | Tech-3 |
| | | | Inability to fully utilize third-party data and crowdsourcing data and services. | Tech-4 |
| | | | Cybersecurity vulnerabilities | Risk-1 |
| | | | Lack of robust data governance rules and scope. | Risk-2 |
| | | | Increased sharing of information with third party can increase security risks. | Risk-3 |
| | Create a data governance and management plan | B.5.2 | Challenges maintaining legacy systems and deploying emerging technology. | Tech-1 |
| | | | Insufficient communication system bandwidth and redundancy for TSMO services. | Tech-2 |
| | | | Inability to fully utilize third-party data and crowdsourcing data and services. | Tech-4 |
| | | | Emerging technology in CAV and Smart Cities uses significant IT resources. | Tech-5 |
| | | | Cybersecurity vulnerabilities. | Risk-1 |
| | | | Lack of robust data governance rules and scope. | Risk-2 |
| | | | Increased sharing of information with third party can increase security risks. | Risk-3 |
| | | | Automated data sets and analyses can mask reliability issues. | Risk-5 |

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U.S. Department of Transportation
Federal Highway Administration
Office of Operations
1200 New Jersey Avenue, SE
Washington, DC 20590

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