

Developing and Using a Concept of Operations for Traffic Management Systems—Current Practices

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FOREWORD

Traffic management systems (TMSs) and Transportation Management Centers are critical resources that offer agencies the potential to improve the safety and mobility of travel on the surface transportation system. TMSs also assist agencies fulfilling the ever-increasing transportation needs of travelers (e.g., travel times), service providers (e.g., transit, emergency services), other agencies, and the public (e.g., incidents). Agencies continue to be challenged with improving the performance of their TMSs; expanding the geographical area they serve; expanding or enhancing services; and providing funding and staffing needed to manage, operate and maintain the systems.

This report identifies current practices and methods to consider when developing or updating a concept of operations (ConOps) and requirements for a TMS. It also discusses how the ConOps and requirements may be integrated into efforts to develop or update the vision, goals, performance measures, or design of a TMS or an agency's operations program. The practices and processes captured in this report may assist agencies when they plan, design, procure, develop, implement, test, operate, and evaluate possible improvements to an existing TMS or the next generation of their system. This report may interest representatives from State departments of transportation, local agencies, metropolitan planning organizations, regional authorities, toll authorities, and other groups whose members may be engaged in developing or using a ConOps when planning, designing, developing, and managing TMSs.

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

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| 16. Abstract This report highlights challenges, opportunities, lessons learned, practices, and issues agencies may consider in the process of updating or developing a concept of operations (ConOps) and the associated requirements for a current traffic management system (TMS) or the next generation of an agency's TMS. It addresses how the ConOps and requirements can be integrated into efforts to assess the feasibility, planning, or designing of new TMSs or efforts to enhance the capabilities or performance of existing systems or specific subsystems or components. The report also addresses how a ConOps and requirements may support developing or updating the vision, goals, performance measures, plan, or design of a TMS or an agency's operations program. This report may interest representatives from State departments of transportation, local agencies, metropolitan planning organizations, regional authorities, toll authorities, and other groups whose members may be engaged in developing or using a ConOps when planning, designing, developing, and managing TMSs. | | | |
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|----------------------------|-----------------------------|-----------------------------|-------------------|
| LENGTH | | | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| AREA | | | | |
| in ² | square inches | 645.2 | square millimeters | mm ² |
| ft ² | square feet | 0.093 | square meters | m ² |
| yd ² | square yard | 0.836 | square meters | m ² |
| ac | acres | 0.405 | hectares | ha |
| mi ² | square miles | 2.59 | square kilometers | km ² |
| VOLUME | | | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| ft ³ | cubic feet | 0.028 | cubic meters | m ³ |
| yd ³ | cubic yards | 0.765 | cubic meters | m ³ |
| NOTE: volumes greater than 1,000 L shall be shown in m ³ | | | | |
| MASS | | | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2,000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| TEMPERATURE (exact degrees) | | | | |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| ILLUMINATION | | | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/m ² | cd/m ² |
| FORCE and PRESSURE or STRESS | | | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/in ² | poundforce per square inch | 6.89 | kilopascals | kPa |

APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|-------------------------------------|-----------------------------|-------------|----------------------------|---------------------|
| LENGTH | | | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| AREA | | | | |
| mm ² | square millimeters | 0.0016 | square inches | in ² |
| m ² | square meters | 10.764 | square feet | ft ² |
| m ² | square meters | 1.195 | square yards | yd ² |
| ha | hectares | 2.47 | acres | ac |
| km ² | square kilometers | 0.386 | square miles | mi ² |
| VOLUME | | | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| m ³ | cubic meters | 35.314 | cubic feet | ft ³ |
| m ³ | cubic meters | 1.307 | cubic yards | yd ³ |
| MASS | | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2,000 lb) | T |
| TEMPERATURE (exact degrees) | | | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| ILLUMINATION | | | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/m ² | candela/m ² | 0.2919 | foot-Lamberts | fl |
| FORCE and PRESSURE or STRESS | | | | |
| N | newtons | 2.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/in ² |

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

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LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|----------|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ADVISE | Adverse Visibility Information System |
| ANSI | American National Standards Institute |
| ATCMTD | Advanced Transportation Congestion and Management Technologies Deployment |
| ATM | active traffic management |
| ATMS | Advanced Traffic Management System |
| Caltrans | California Department of Transportation |
| CCTV | closed-circuit television |
| CHART | Coordinated Highway Action Response Team |
| CMF | capability maturity framework |
| CMM | capability maturity model |
| ConOps | concept of operations |
| DART | Dallas Area Rapid Transit |
| DB | design–build |
| DBB | design–bid–build |
| DCA | Data Collection and Archiving |
| DLUC | dynamic lane use control |
| DMS | dynamic message sign |
| DOT | department of transportation |
| DUAP | data use analysis and processing |
| EPA | U.S. Environmental Protection Agency |
| FDOT | Florida Department of Transportation |
| FHWA | Federal Highway Administration |
| GDOT | Georgia Department of Transportation |
| HAR | highway advisory radio |
| https | hypertext transfer protocol secure |
| IADOT | Iowa Department of Transportation |
| ICM | integrated corridor management |
| ID | identifier |
| IEM | Incident/Event Management |
| IMTMS | Intermodal Transportation Management System |
| IOS | integration with other systems |
| IT | information technology |
| ITS | intelligent transportation systems |
| JTMC | Joint Traffic Management Center |
| KC Scout | Kansas City Scout |
| LAN | local area network |
| MDOT | Michigan Department of Transportation |
| MDSHA | Maryland State Highway Administration |
| MnDOT | Minnesota Department of Transportation |
| MOBILE | Mobile Source Emissions Model |
| MoDOT | Missouri Department of Transportation |
| MOVES | MOtor Vehicle Emission Simulator |
| MPO | metropolitan planning organization |

| | |
|---------|---|
| MTP | metropolitan transportation plan |
| NextGen | next generation |
| NFTA | Niagara Frontier Transportation Authority |
| NITTEC | Niagara International Transportation Technology Coalition |
| NMDOT | New Mexico Department of Transportation |
| PeMS | Performance Measurement System |
| RAMS | Regional Arterial Management System |
| RFP | Request for Proposals |
| ROF | regional operations forum |
| RTOP | Regional Traffic Operations Program |
| RTP | regional transportation plan |
| RWIS | road weather information system |
| SDOT | Seattle Department of Transportation |
| SHRP2 | Second Strategic Highway Research Program |
| SMART | Suburban Mobility Authority for Regional Transportation |
| SRTMC | Spokane Regional Transportation Management Center |
| TIM | traffic incident management |
| TIP | transportation improvement plan |
| TM | Traffic Management |
| TMC | traffic management center |
| TMS | traffic management system |
| TOC | transportation operations center |
| TOPS-BC | Tool for Operations Benefit-Cost Analysis |
| TSMO | transportation systems management and operations |
| TSP | transit signal priority |
| TxDOT | Texas Department of Transportation |
| UDOT | Utah Department of Transportation |
| USDOT | U.S. Department of Transportation |
| VCTMC | Virtual Corridor Traffic Management Center |
| VDOT | Virginia Department of Transportation |
| VSL | variable speed limit |
| WSDOT | Washington State Department of Transportation |
| WYDOT | Wyoming Department of Transportation |
| XML | Extensible Markup Language |

CHAPTER 1. INTRODUCTION

This report identifies current practices and methods that agencies may consider to support developing, updating, or using a concept of operations (ConOps) and the requirements for a traffic management system (TMS). This report explores how agencies may consider and integrate the ConOps and TMS requirements when assessing the feasibility of making changes; planning for potential improvements; or designing, managing, operating, or evaluating an existing or the next generation (NextGen) of an agency's TMS. This report also discusses the relationship between the ConOps and TMS requirements within planning processes, including regional strategic plans (e.g., metropolitan planning organization (MPO) transportation plan), agency plans (e.g., strategic plan), operations program plans (e.g., transportation systems management and operations (TSMO) plans), multiyear operating plans, and initiatives or efforts to assess the allocation of agency resources.

This report identifies the following specific objectives:

- How to consider current challenges, opportunities, lessons learned, and issues when developing or updating a ConOps and requirements for a TMS.
- How the ConOps and requirements may be integrated into efforts to develop or make updates to the vision, goals, performance measures, plan, or design of a TMS or the agency's TSMO program and plans.
- How the ConOps and requirements for an existing or NextGen of an agency's TMS may be used as inputs into an agency's or region's planning processes and how the latter can be an input to the ConOps and requirements.

Agencies are continuously seeking ways to do more with their limited budgets. Agencies make difficult decisions on how to allocate their budgets to get the best return on their investments while still ensuring they are providing a safe traveling environment. State departments of transportation (DOTs) and local transportation agencies continue to explore opportunities to improve how they manage and operate traffic. These efforts often lack the development of strategic plans or initiatives to prepare for future improvements to their TMSs. Often, the current or future needs of TMSs are typically not incorporated into the strategic, planning, or programming efforts of TSMO programs or plans.

Planning for the NextGen of an agency's TMS can identify opportunities to improve the capabilities and pursue the supporting improvements. TMSs capable of actively managing traffic and operating TMSs offer agencies the opportunity to incrementally improve safety and the operation of their surface transportation systems. TMSs provide agencies with the ability to proactively monitor, assess system performance, apply strategies, and evaluate and recommend actions to improve the use of operational strategies and selected action(s). The active management and operation of a TMS allows for the adjustments to the management and operation of different strategies and control plans based on projected, current, or anticipated future conditions. Figure 1 illustrates this active management cycle.



Source: Federal Highway Administration (FHWA).

Figure 1. Diagram. The active management cycle.⁽¹⁾

Agencies are challenged with planning, designing, procuring, deploying, improving, or replacing their TMSs. Regardless of the size (e.g., area of coverage), functionality, or capabilities of the system, agencies continually have the need to assess and evaluate the feasibility of future enhancements to their TMSs. Although these investments can be costly, assessing and planning for possible improvements are intended to ensure the investments meet current and future needs of the agency and other stakeholders. Agencies plan for improvement and maintenance of the surface transportation network, and the resulting plans cover many modes, addressing needs as far out as 20–25 yr. Agency strategic plans, as well as short-term plans like a (statewide) transportation improvement plan (TIP), TIP for a metropolitan area, or a TSMO plan provide a blueprint for investments and resource allocation.

For roadway infrastructure projects (e.g., regional, corridor, or facility), established processes assess feasibility of different projects, evaluate improvement options, consider design alternatives, and obtain feedback from users and local agencies. These processes inform the decisionmaking that occurs in planning, programming, developing projects, and implementing and constructing selected roadway improvement projects. Agencies have established processes to conduct feasibility and planning studies (to evaluate and consider possible alternative roadway improvements) that support identifying and selecting improvements before initiating the design, procurement, and construction of the projects.

The ConOps contains information pertaining to a TMS to assist with reviewing current capabilities and performance of a TMS and in planning possible improvements. The ConOps describes the operating environment in a nontechnical manner, presenting this information from multiple viewpoints, along with identifying the needs of agencies and stakeholders. The ConOps and subsequent requirements are both derived from and are inputs to transportation planning and, as such, support agency and regional objectives.

The ConOps describes how a system will be used and identifies the fundamental needs of all stakeholders involved throughout the lifecycle of a system. A ConOps may be developed for the following reasons:

- Gain stakeholder agreement regarding how the TMS is to be operated, who is responsible for what, and what are the lines of communication.
- Define the high-level system concept and justify if it is superior to the other alternatives.
- Define the environment in which the system currently operates and will operate in the future.
- Derive high-level requirements, especially user requirements.
- Provide the criteria to be used for validation of the completed system.
- Enable stakeholders to agree on what the functionality of a TMS will serve.

Once the ConOps sets out the vision, goals, user needs, operational needs, high-level system concepts, etc., requirements for the system can be defined. The requirements follow and define what the TMS does. The ConOps describes how the TMS is used, is nontechnical, and is presented from the viewpoints of the various stakeholders. This process provides a bridge between the needs that motivated the project initially and the specific technical requirements. The requirements lay out the groundwork for the development of the technological components of a TMS and include both functional and operational requirements (i.e., what the system is).

Pursuing investments in TMSs without a well-thought-out ConOps and clear technical requirements may hinder an agency's ability to match its plans to the available resources and capabilities needed to manage, operate, and maintain its TMS. Planning for developing, installing, and operating a TMS is a process that is most effective when driven by objectives and desired outcomes. Similarly, the ConOps and requirements serve as input to the planners, providing insight into regional capabilities, policies, needs, and lessons learned from the ConOps development based on stakeholder objectives.

During the development of TMSs, agencies may consider the following activities:

- Planning and developing new or enhanced TMSs.
- Planning and developing TMSs that are modular and facilitate future expansion or enhancements.
- Developing and procuring new or upgraded TMSs or subsystems.
- Ensuring current and expected future resources and capabilities (e.g., staffing) align with the capabilities and requirements of existing TMSs or planned future improvements.

INTENDED AUDIENCE

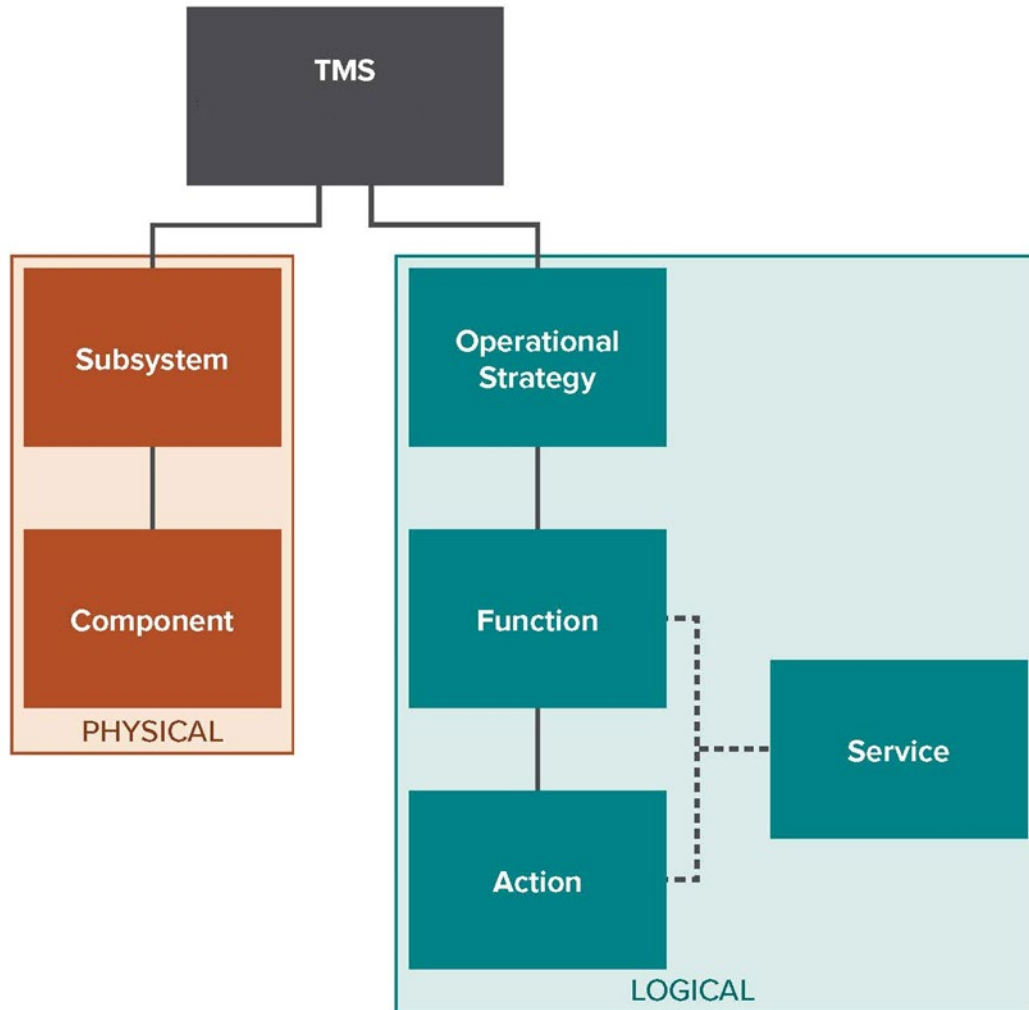
This report is written for a range of individuals who are involved in, support, or responsible for planning, developing, designing, managing, operating, and maintaining TMSs. Individuals who also would benefit from reading this report include those involved with agency or regional strategic operations program planning (e.g., TSMO plan) and multiyear operating plans, initiatives, or efforts to assess the allocation of agency resources. These individuals may include representatives from State DOTs, local agencies, MPOs, regional authorities, toll authorities, or other groups involved with or who support TMSs. In addition, consultants, contractors, and researchers also may benefit from reading this report.

CONTEXT OF TMSs

A TMS comprises an often complex, integrated blend of hardware, software, processes, and people performing functions and actions. TMSs are focused on improving the efficiency, safety, and predictability of travel on the surface transportation network. TMSs present new opportunities for agencies to improve their capabilities by more actively managing and monitoring their networks using emerging technologies and data sources.

The more complex TMSs comprise multiple subsystems, and these subsystems have become more multifaceted as the technology and components that make up these systems have evolved. A subsystem is a group of self-contained and interactive components that support one or more operational strategies as a part of a TMS.

The design or structure of a TMS has both physical and logical elements. Physical elements include the subsystem and the components. Logical elements include the operational strategies, functions, actions, and services. Figure 2 shows a visual representation of the TMS structure. Note that the lines in the diagram depict the relationships for both the physical side and the logical side of a TMS; they do not depict a flow of data or information.



Source: FHWA.

Figure 2. Flowchart. General TMS structure.⁽²⁾

WHAT IS A CONOPS AND REQUIREMENTS FOR A TMS?

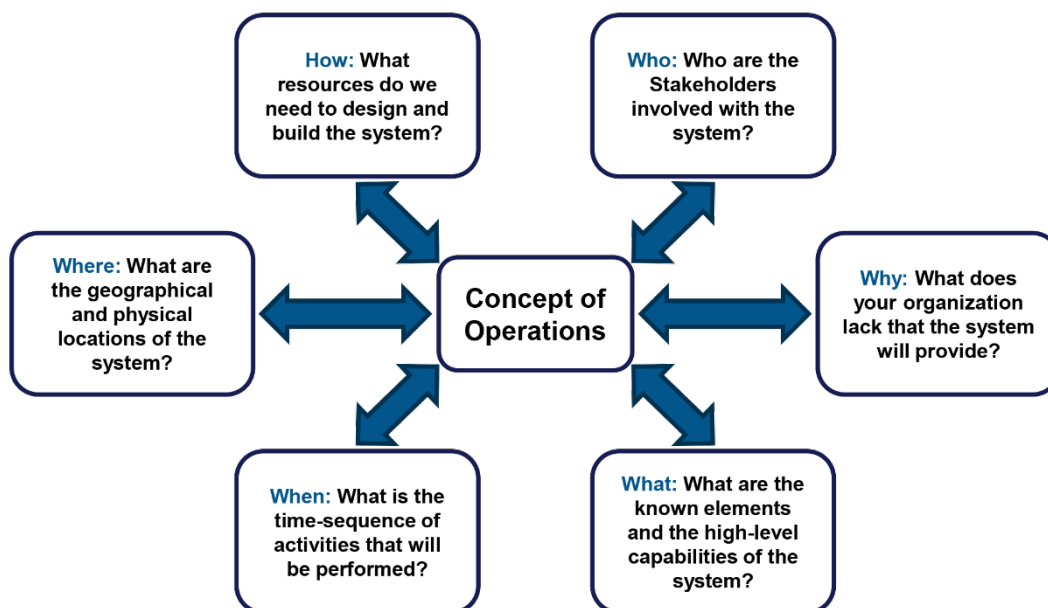
A ConOps describes how a system will be used and identifies the fundamental needs of all stakeholders involved throughout the lifecycle of a system. The ConOps is a key element that is included in the planning, design, development, and operation of a TMS or an agency’s TSMO program and plans. The ConOps is intended to be written for a nontechnical audience, in an easy-to-understand manner, presenting information connecting agency and stakeholder needs to the requirements that a TMS may need to support. The ConOps typically includes the TMS needs and expectations for different stakeholders it may support or collaborate with for different events or scenarios. A thorough discussion of a ConOps continues in chapter 3 of this report.

The ConOps should be considered in all phases in the TMS lifecycle (e.g., planning, design, development, operation) that may involve planning or investments to support the active management and operation of a TMS. Updates for the ConOps reflect the current capabilities and

desired performance of a TMS. Updates to the ConOps are appropriate through the lifecycle of a TMS to reflect the changing needs and future capabilities needed by an agency's TMS.

ConOps often include operational scenarios, use cases, and user needs that ensure all stakeholders understand how the TMS operates and their respective roles in managing traffic and responding to different events. It provides a bridge between the initial need for a specific improvement project and the technical needs and requirements of the TMS. ConOps also provide the necessary institutional and technical information that may be needed to integrate the TMS project throughout an agency's strategic and program plans.

At its core, the ConOps answers the who, what, when, where, why, and how and the needs and expectations to consider when planning to improve an existing or prepare for the NextGen of an agency's TMS. Figure 3 illustrates some examples of these questions.



Source: FHWA.

Figure 3. Flow diagram. Major questions the ConOps will answer.⁽³⁾

The ConOps may *not* identify a specific technical solution for a TMS, a specific subsystem, or component. However, the ConOps may be used to explain conceptually the current or desired future characteristics, capabilities, or performance of the NextGen of the agency's TMS.

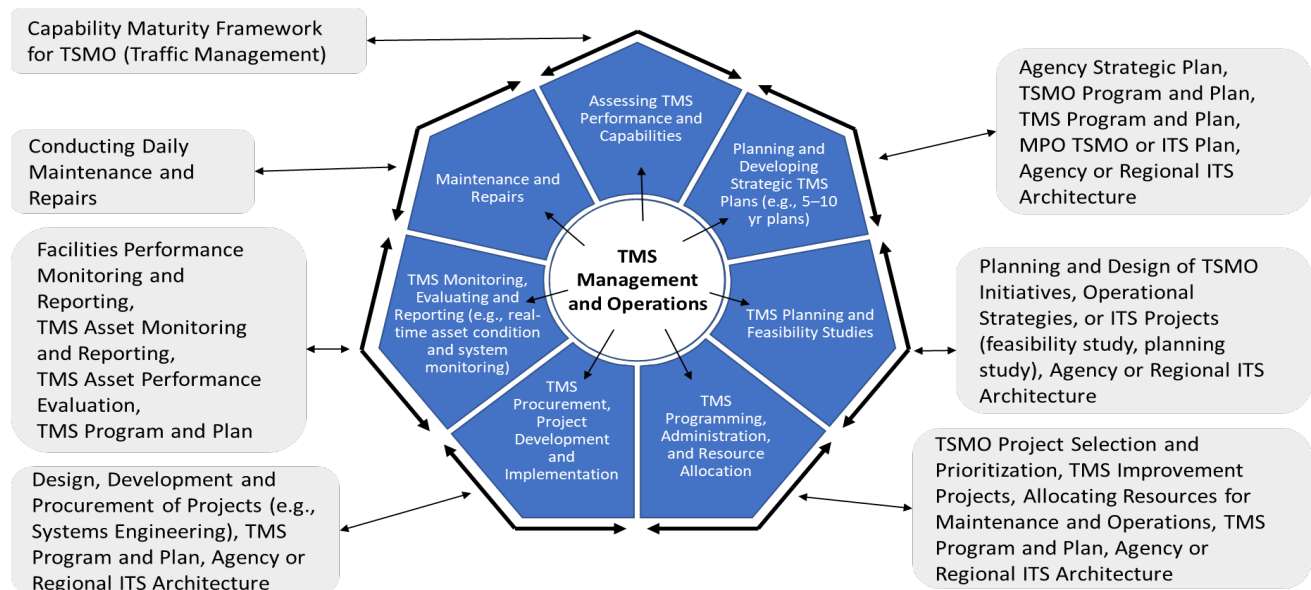
Developing a ConOps for a TMS typically involves a review of plans, such as an agency's strategic plans or program plans, for insight and input into the following parameters:

- Overarching institutional goals, objectives, and preferences.
- Stakeholder identification.
- Agency mission, function, responsibilities, and scope.
- Capital and operating funding.
- Operational policies and procedures.
- Regional infrastructure and facilities.

Similarly, plans and planning procedures, such as intelligent transportation systems (ITS) architectures and regional ConOps already may have documented, summarized, or identified information that could be used to provide insight into the following elements:

- Institutional goals, objectives, and preferences.
- Stakeholders, their roles, and information they need to support different types of events.
- Functions to be supported by a TMS.
- Functions supported by a TMS specific to different services or actions in a region.
- Equipment, technology, facilities, people, and systems available regionally for transportation needs.
- Stakeholders' funding sources.

The input is not unidirectional in this process because the ConOps provides feedback to the larger planning process from its scenario and use-case planning. The ConOps focuses on how the TMS may be operated and managed under different local conditions, such as planned events (e.g., sporting events, construction work zones), incidents (e.g., closed lanes or inclement weather), and typical day-to-day operations. These scenario planning and use-case development exercises yield information important to the larger agency planning process, such as local needs, current local operational and system capabilities, and future capabilities in the region. Figure 4 illustrates the relationship between the TMS, ConOps, and possible planning processes that may be appropriate to integrate the capabilities and performance of a TMS.



Source: FHWA.

Figure 4. Diagram. Processes and activities supporting TMS management and operations.⁽⁴⁾

The following consequences of not using the ConOps and requirements are significant:

- A disparate assembly of subsystems that do not work in conjunction with each other.
- A system, when built, that does not provide the functionality necessary to the users.
- Extensive and costly upkeep.
- Costly modifications.
- Extended project development cycles.
- Inability to share information between subsystems or other TMSs.

In terms of the “V Diagram” systems engineering process, the requirements effort immediately follows the ConOps development.⁽⁵⁾ The ConOps serves as a link from the planning processes to the decisionmaking processes. For this reason, the ConOps also is the foundational step prior to the requirements being developed. The requirements will lay out the groundwork for the development of the technological components of a TMS and include both functional requirements (i.e., what the system is supposed to do) and performance requirements (i.e., how well the system performs its functions). With a well-defined ConOps, developed with stakeholder involvement, and knowledge of the environment in which the system will exist, generating the requirements becomes more feasible. System requirements are discussed in further detail in chapter 5, and the development of requirements is outlined in chapter 7 of this report.

REPORT ORGANIZATION

This report captures the current and evolving practices used by agencies in reviewing, updating, developing, and using a ConOps for an existing or NextGen TMS. From a scan of available literature and discussion with industry practitioners, this report highlights challenges, opportunities, lessons learned, best practices, and important factors or issues agencies consider in the process of developing or using a ConOps and associated information. This report also addresses how the ConOps and requirements of an existing TMS can be integrated into efforts to assess the feasibility, planning, or design of a new system. It also includes efforts to enhance the capabilities or performance of existing systems or specific subsystem or components.

This report includes seven main chapters organized as follows:

- **Chapter 1. Introduction.** This chapter presents the purpose of the report, introductory information on the TMS, ConOps and requirements, integration with the planning process, the general structure of the ConOps and requirements, the benefits of using this report, who would benefit from reading this document, and the overall organization of the report.
- **Chapter 2. TMSs and Capabilities.** This chapter introduces and describes different types of TMSs available to agencies, along with mention of current practices and how TMSs are being actively managed and operated.

- **Chapter 3. What Is a ConOps?** This chapter provides information on what a ConOps is and how it can be used in the planning and design of a TMS. It describes the core elements of the ConOps and the information that is included in each element, using detailed examples from agencies' efforts to develop a ConOps for the NextGen of their TMS.
- **Chapter 4. TMS ConOps and Planning.** This chapter walks through the process of planning, developing, and implementing a system, agency policies, and industry trends and practices. It describes the interrelationship between the ConOps and larger agency planning processes.
- **Chapter 5. The ConOps and Project Development.** This chapter discusses the next level down from the larger agency and regional planning processes previously described. It addresses how detailed identification of projects are derived from the larger planning process and the project-specific feasibility planning and development of a specific project from which the ConOps is derived.
- **Chapter 6. Developing a ConOps.** This chapter provides guidance on ConOps development. Unlike the more generic discussion of the ConOps in previous chapters, this chapter directly addresses NextGen TMS ConOps.
- **Chapter 7. Developing and Using TMS Requirements.** This chapter introduces requirements, describes the purpose of requirements in the procurement of a TMS, how requirements are derived from the ConOps, and what constitutes a good requirement.

CHAPTER 2. TMSs AND CAPABILITIES

This chapter discusses the components of a TMS, and to explain what they are capable of. It opens with a general overview of TMSs by describing the physical and logical elements. Additionally, this chapter explains what a (legacy) TMS is, what a NextGen TMS is, major differences between the two, and how these issues are considered in regional or agency strategic plans and programs. It discusses what types of TMSs are available to agencies and how they are actively managed and operated per facility. Chapter 2 allows for readers to gain an overall understanding of TMSs through discussions about where the TMS is heading in the future. Distinguishing the differences between the legacy and NextGen TMSs is important to better understand their capabilities for regional and agency programs. Additionally, the information in this chapter provides the background for chapter 3's discussion of developing a ConOps.

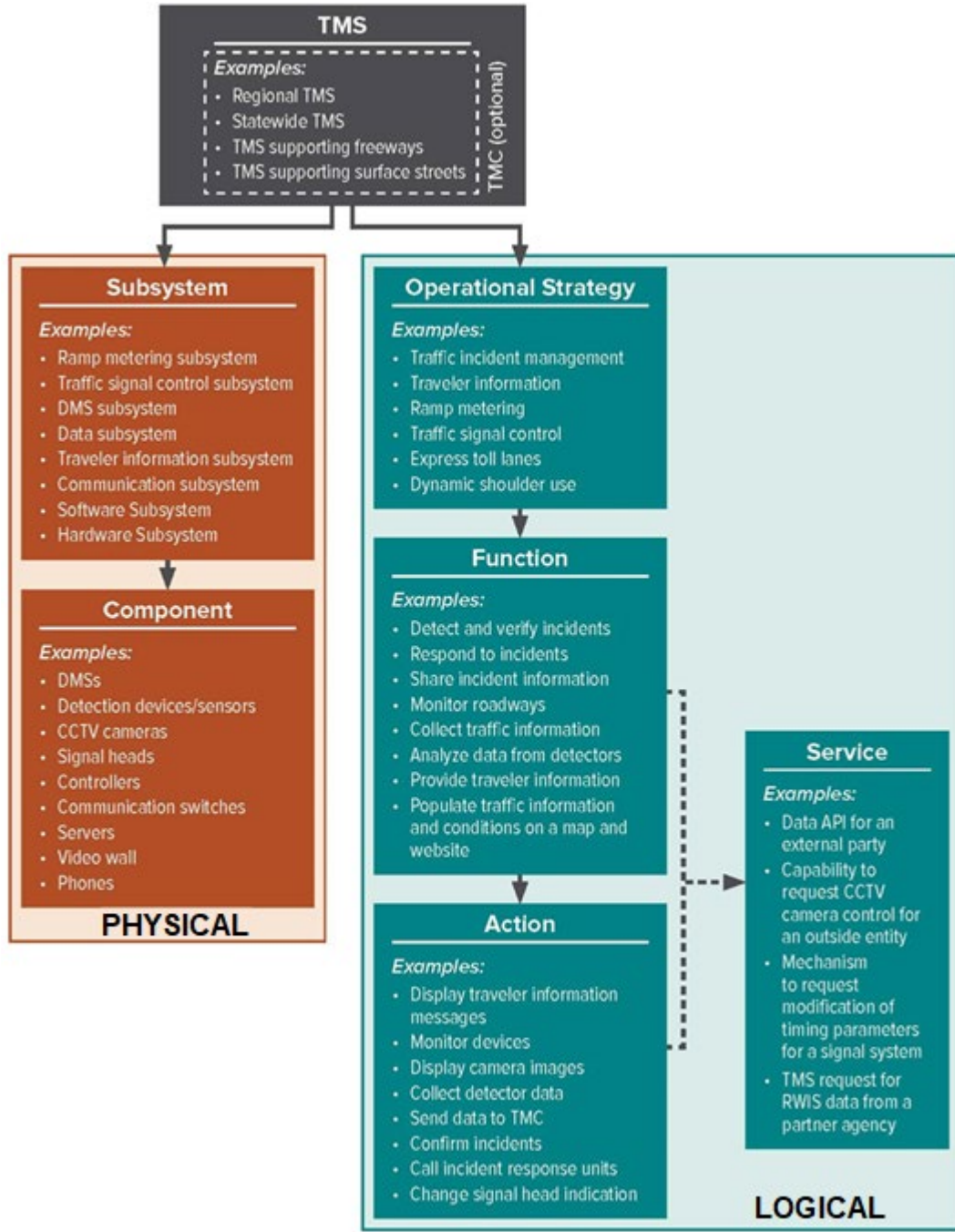
OVERVIEW OF TMS TYPES

The TMS structure has both physical and logical elements. Physical elements include the subsystems and components. Many TMSs have a physical traffic management center (TMC) that acts as the nerve center of the system, while others do not and may not ever have one. Regardless of whether a TMS is controlled by a TMC, modern TMSs are complex systems and typically comprise a suite of subsystems. The subsystems themselves often comprise an integrated collection of components or ITS components. The logical elements are the operational strategies, functions, actions, and services. In computer terminology, a logical element converts inputs into appropriate outputs. Similarly, for a TMS, the logical element takes input from physical components and executes operational strategies that have a direct output meant to satisfy a functional or operational need. How these logical elements are implemented is based on the type of roadway being managed, the agency's need, and the geographical extent of the agency's jurisdiction.

A TMS generally can be included in TIPs, long-range plans, and short-range plans if it can support the plans' goals and objectives. These plans are where proposed TMS enhancements (e.g., added functionality), expansion (e.g., area of coverage), new capabilities, or an entire replacement of a TMS need to be integrated into multiyear budget plans. All the needs and supporting projects in a TMS study help bolster the prioritization, justification, definition, and scope necessary to support the integration of a project into an agency's multiyear plan and budget for all capital or operational expenditures (e.g., MPO TIP).

As a result of planning for the implementation of a TMS, a multiyear TMS plan that identifies resources, future projects, and procurement methods is captured. The TMS plan, or elements of the plan, can be included in agency transportation or TSMO plans, capital programs, and budgets. Key elements of the plan include identifying links to the agency's TSMO and long-range scenario plans, MPO long-range plans, and other agency plans. TMS development, project integration, and funds allocation in future budgets provide the resources needed for the agency to implement the plan. The multiyear plan identifies any enhancements or improvements that may be needed over a 5–10-yr period, ongoing operations and maintenance requirements, and administration needed to support the TMS over the planning horizon.

By providing some context for both the physical and the logical sides of a TMS and examining how these strategies have evolved over time, researchers can better understand the changing needs of an agency and how it has evolved to meet current needs. Figure 5 provides the TMS structure with examples.



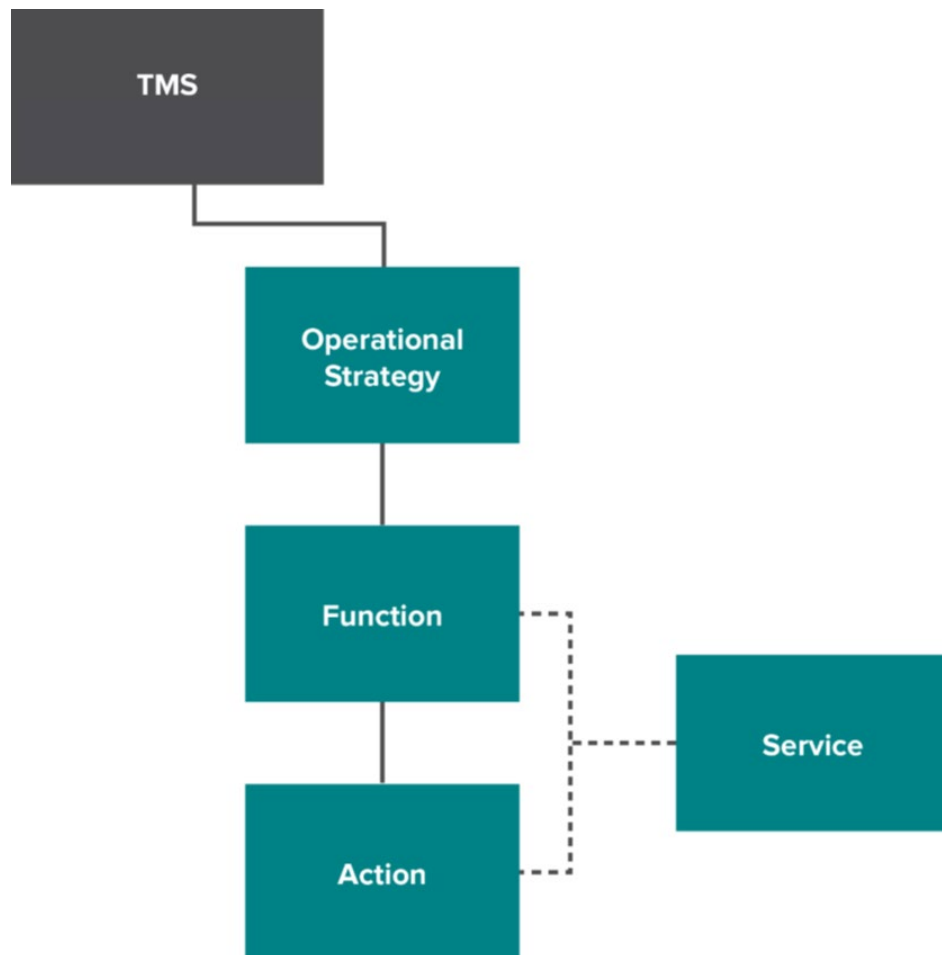
Source: FHWA.

API = application programming interface; CCTV = closed-circuit television; DMS = dynamic message signs; RWIS = road weather information system.

Figure 5. Flowchart. General TMS structure with examples.^(2,4)

LOGICAL ELEMENTS OF A TMS

The logical elements of a TMS consist of the operational strategies, functions, actions, and services that are implemented in different environments. Figure 6 displays the logical side of the TMS structure.

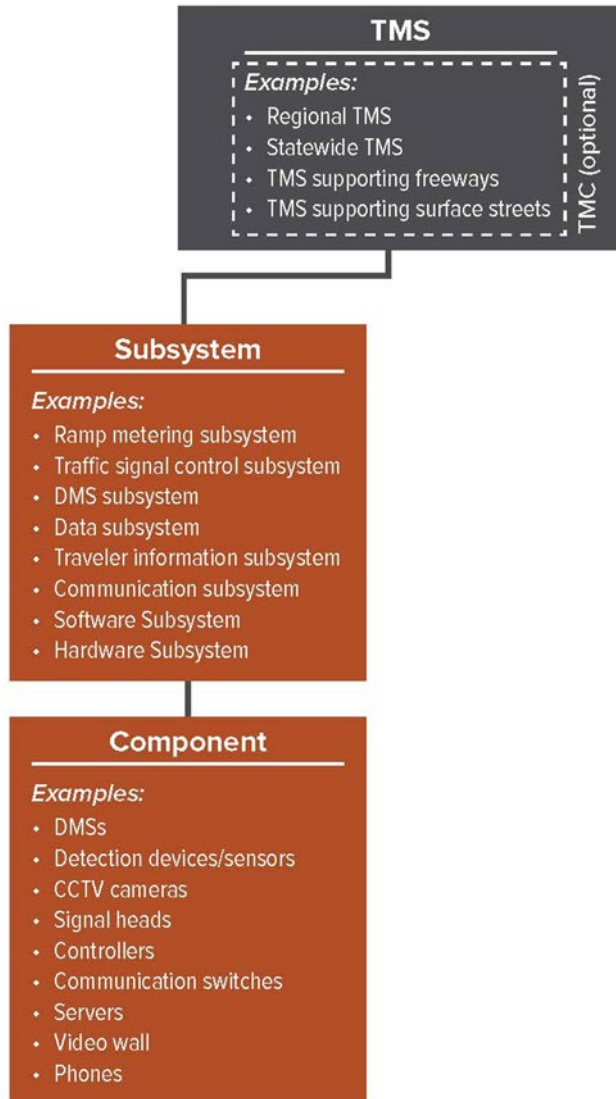


Source: FHWA.

Figure 6. Flowchart. General TMS structure (logical side).⁽²⁾

PHYSICAL ELEMENTS OF A TMS

Many TMSs have a physical TMC that acts as the nerve center of the system, whereas other TMSs may consist of a computer or a tablet on a desk. Regardless of whether a TMS is controlled by a TMC, modern TMSs are complex systems and are typically composed of a suite of subsystems. The subsystems are often made up of an integrated collection of components or ITS components. Figure 7 shows the physical side of the TMS.



Source: FHWA.

Figure 7. Flowchart. General TMS structure (physical side).⁽²⁾

Subsystems are often deployed together to enable various operational strategies that are intended to meet agency goals. Components from these subsystems can range from dynamic message signs (DMS), detection components, closed-circuit television (CCTV) cameras, signal heads, controllers, communication switches, and other computer technologies. These components may work in isolation from one another or may work in concert with components serving other subsystems to perform functions to achieve the overall objectives of the system.

The selection of ITS components and technologies can be guided by the operational strategies that an agency is trying to implement, the subsystem architecture and how the components are linked to the subsystems, and how these strategies and systems work together to meet overall agency goals, objectives, and performance measures.

TYPES OF TMSs

This section addresses the range of architectures, subsystems, components for subsystems, operational strategies, functions, actions, and services supported by TMSs. By considering individual parts of the system, agencies can evaluate how systems are carrying out needed functions, overall system performance, and (if necessary) the need to make changes in how a TMS is actively managed and operated. Additionally, agencies can modify how operational strategies or services are being deployed and upgrade or replace individual components or the entire system as needed. In addition to providing some context and examining how these systems operate, this section includes examples and current practices in successful implementation of TMSs for systems that support freeways, surface streets, and facilities or corridors or regions.

By presenting examples of how these subsystems and their components are supposed to operate, or how they are intended to perform, agencies can better understand where their current capabilities lie (and if improvements are to be made). Gaining an encompassing understanding ultimately assists in the future development or upgrade of a ConOps. The development and planning of a ConOps is further discussed in chapter 6 of this report.

Before breaking down the types of systems that support freeways, surface streets, and facilities or corridors or regions, understanding the different operating models is important. From a logical perspective, several different types of operating models are used for TMSs. The operating model is a characteristic of a TMS. Some of the most common types of TMS operating models in the United States include virtual, centralized, distributed, and hybrid TMSs.⁽²⁾

Virtual TMSs

The virtual model involves the use of communication, computing, and software technology to manage and operate TMSs without a physical nerve center or TMC. The most common approaches to applying this model include staffing and operation by a single entity or management by a single entity with support from other partner agencies. Depending on the scale that this model is applied (in terms of jurisdiction, geographical area, operational strategies, and scope), extensive coordination from participating agencies may be required. An interagency agreement may be required. Access to this virtual system may be available to both agency and interagency personnel. By using the virtual model, participating agencies can share costs; alternatively, this model may be funded by a single entity.

Centralized TMSs

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

Distributed TMSs

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

Hybrid TMSs

The hybrid model combines the virtual model with the centralized and distributed models. This model can be further categorized into hybrid centralized and hybrid distributed, and it can apply to an extended geographical area, including urban and rural regions. In the hybrid centralized submodel, a single entity and all users within that entity share the same network. This network can be accessed via an Intranet or a virtual private network. In the hybrid distributed submodel, multiple participating entities access the TMS on the Internet using the hypertext transfer protocol secure (https) communications protocol.

In other words, users can access the system from any location with Internet connectivity. Some level of restrictions typically applies for the type of access allowed for specific groups of users and specific functionalities. Currently, many TMSs in the United States have virtual capabilities; however, these capabilities are typically established for emergency and backup operations rather than as a primary stand-alone hybrid model.

Operational Strategies that Support Freeways

This section discusses the commonly used operational strategies incorporated in TMSs⁽²⁾ to achieve agency goals and objectives for managing freeways. Traffic operations strategies encompass a set of functions and actions to improve the management and operation of the roadway network, optimize performance, and improve safety. Deployment of operational strategies is informed by agency goals, policies, procedures, and associated performance metrics.

In the sixties and seventies, freeway-focused operational strategies performed by TMSs primarily relied on basic functions such as monitoring traffic conditions, identifying incidents, and collecting traffic data. As time went on, agencies started using that data to enhance their operational strategies. Functions evolved from basic monitoring and data collection to regulating access, managing incidents, providing traveler information, and other tasks.

As technology continues to evolve, so too has the functionality to collect and manage more complex forms of data. This evolution shapes the way agencies implement operational strategies because they can leverage more data to make informed decisions. As agencies upgrade their components and software, the timeframe for decisionmaking and responding to changing conditions has improved. The U.S. Department of Transportation's (USDOT) Active Transportation and Demand Management Program categorizes the level of responsiveness of operational strategies.⁽¹⁾

- Static—Strategy responses to variations in conditions are preset and updated based on the calendar.
- Reactive—Strategy responses occur when problems are observed with the static plans, requiring real-time monitoring.
- Responsive—Strategy responses to variations in conditions occur in realtime after they are detected.
- Proactive—Strategy responses are adjusted in anticipation of future conditions.

Most agencies have implemented, and are managing the use of, operational strategies at the static level. The evolution of technology and data management functionality has allowed agencies to move toward reactive, responsive, and proactive levels of operational strategy implementation. An example of an operational strategy in the freeway environment that is deployed at the static level is time-of-day ramp metering (i.e., preset ramp metering rates that change based on timeframes set by an agency). As agencies install detection apparatus to monitor volumes on the ramps and mainline, they can use these data to automatically change their operational strategy to become reactive and responsive to changing conditions. An agency that operates ramp metering at the proactive level is able use both real-time and historical data to predict future conditions and implement ramp metering before congestion occurs.

As data collection and management functionality continues to improve, so has the range of available data. For example, crowdsourced data enables agencies to provide better traveler information and be more responsive in deploying operational strategies to respond to reported congestion, incidents, and weather conditions.

Freeway operational strategies may range from one freeway through an urban or rural area, to several freeways throughout an urban or rural area, to one or more freeways throughout an entire State. The main objectives of a TMS that supports freeway operations strategies are to maximize traveler safety, eliminate or minimize the duration of congestion, reduce travel time impacts, reduce the severity of or eliminate traffic incidents, and provide drivers with necessary information required to make informed travel decisions.

TMSs in the freeway environment are not limited to managing recurring conditions in a single agency network. They also can support a range of functions related to short-term objectives, such as temporary systems, or several objectives shared by multiple agencies, such as multiagency systems, statewide systems, and even support objectives shared across State lines such as multi-State systems.

Operational Strategies

Operational strategies are designed to achieve specific goals or objectives that can be clearly identified and measured. The performance of the operational strategy can be measured to determine the effectiveness of reaching the intended objectives. Often, a suite of operational strategies is needed to reach these goals. Agencies can deploy many operational strategies to support freeway operations. The following operational strategies are the more common ones:⁽²⁾

- Ramp metering.
- Managed lanes.
- Variable speed limit (VSL).
- Dynamic speed advisory/harmonization.
- Traffic incident management (TIM).
- Part-time shoulder use.
- Traveler information.
- Road weather management.
- Queue warning.
- Weigh-in-motion.
- Work zone management.
- Data management.

Functions

Operational strategies are enabled by specific functions and actions. The following functions can be implemented to support these operational strategies:

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

Actions

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

- Monitoring components.
- Collecting data from detectors (including traffic and roadway conditions data).
- Collecting weather data.
- Sending data to storage.
- Sending data to another system or party.
- Sending data to a TMC.
- Displaying traveler information and public advisories on DMSs.
- Displaying speed advisories on lane control signs.
- Broadcasting travel advisories or anticipated travel delays using highway advisory radio (HAR).
- Displaying CCTV camera images on a video wall or website.
- Releasing information or conditions invoking a decision, action, or information sharing.
- Confirming incidents.
- Calling incident response units.
- Calling maintenance crews.
- Changing the ramp meter signal head indication.

Services

Operational strategies also are typically supported by services. These services, with the help of communication mediums and mechanisms, are a set of functions and actions that allow for system access to be enabled for external parties. The following examples of services can be implemented for operational strategies in the freeway environment:

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

- A mechanism that allows onboard connected vehicle equipment installed on freight vehicles to communicate with the road weather management and data management subsystems to display speed advisories in the vehicle when weather conditions limit visibility. This service also can supplement the dynamic speed advisory operational strategy.
- An interface that allows data and information to be exchanged between the road weather information systems (RWISs) and a regional or agency TMS. Most RWISs are separate from TMSs; this service helps to facilitate that data exchange. This service supports the road weather management and data management strategies.
- A method that allows data exchange between the road weather TMS and the National Weather Service. This service supports the road weather management and data management strategies.
- A method (e.g., software, algorithms) that monitors, assesses, and offers (e.g., meeting a congestion threshold trigger) multiple optional responses from which the best alternative is then selected. This method is often referred to as decision support.

Operational Strategies That Support Surface Streets

This section examines the commonly used operational strategies incorporated in TMSs to achieve agency goals and objectives for managing surface streets. These operational strategies may be integrated into a TMS that could include responsibilities for a region or corridor and include interconnection with other TMSs.

Traffic signal control is one of the primary strategies that local agencies deploy to manage traffic on surface streets. However, TMS deployment has expanded to include a range of operational strategies, functions, and actions to support regional mobility and access objectives for a rapidly expanding population and growing economy.

Operational strategies such as traffic signal controls have the basic function of regulating and controlling traffic movements at intersections with traffic signals. Much like operational strategies deployed in freeway environments, agencies began to leverage the increases in available data, data collection methods, and communication technologies to enhance their surface street environment strategies and expand their functionality.

Operational strategies such as traffic signal control evolved from using pretimed and time-of-day functions to collecting real-time data to implement adaptive signal control functions. The degree of data collection and management functionality of a system dictates the type of surface street operational strategy an agency implements. The improved data collection capabilities of the systems enhanced the strategies by improving functions related to traffic management, traveler information, incident management, coordination, and performance measurement. For example, many traffic signal control strategies that use real-time signal controller data can revise signal timing schemes (or notify an operator to modify schemes) in response to changing traffic conditions and inform agency personnel on the performance of the system before and after the changes.

Operational Strategies

Agencies can deploy many operational strategies to support surface street operations. The following operational strategies are the more common ones:

- Traveler information.
- Traffic signal control.
- TIM.
- Transit signal priority (TSP).
- Emergency vehicle preemption or priority.
- Managed lanes.
- Parking management.
- Special event management.
- Emergency management.
- Data management.

Functions

Operational strategies comprise of specific functions and actions. The following functions support these operational strategies:

- Collecting traffic information.
- Analyzing the collected data.
- Disseminating traveler information.
- Providing traffic detection and surveillance.
- Providing priority for transit vehicles at signalized intersections.
- Providing preemption for emergency vehicles at signalized intersections.
- Managing incidents and special events.
- Collecting parking availability information.
- Providing coordination among agencies.
- Monitoring and evaluating system performance.

Actions

These functions are composed of basic and singular actions that are performed by a person or a TMS component. The following actions comprise these functions:

- Monitoring components and traffic signal equipment.
- Collecting data from detectors.
- Sending data to storage.
- Sending data to another system or party.
- Sending data to a TMC.
- Displaying traveler information on DMSs.
- Displaying CCTV camera images on a video wall or website.
- Confirming incidents.
- Calling incident response units.

- Calling maintenance crews.
- Changing the traffic signal head indication.

Services

Similar to the freeway operating environment, operational strategies in the surface street environment are often supported or enhanced by services. These services, facilitated through communication mediums, comprise a suite of functions and actions that allow data exchange to occur with external systems. The following examples of services can be implemented in the surface street environment:

- A mechanism that allows a third-party traveler information provider to exchange data with the agency's traveler information and data management subsystem to leverage data from both subsystems to provide travelers with more comprehensive information. This service also may supplement TIM, emergency management, and special event management strategies.
- An interface that allows data and information to be exchanged between a local agency operating in a surface street environment and a State agency operating in a freeway environment. Many operational strategies are applied to surface streets and freeway facilities separately due to systems operating within their respected jurisdictions. This service allows these agencies and strategies to be coordinated to improve effectiveness at a larger scale. This service may support traveler information, TIM, special event management, emergency management, and data management strategies.
- A method that enables communication between onboard equipment installed on transit vehicles and the traffic signal control subsystem to enhance TSP functionality. This service supports the TSP, traffic signal control, and data management operational strategies.
- An application programming interface that allows enforcement agencies to access data from the parking management subsystem. This service can enhance the parking management strategy by providing enforcement agencies with information on potential parking violators when facilities are near capacity. This service also may supplement special event management, emergency management, data management, and operational strategies.

Operational Strategies That Support Multiple Facilities, Corridors, or Regions

The basic premise behind managing multiple facilities, corridors, or locations—as well as for an integrated corridor management (ICM) approach—is to jointly manage and operate individual TMSs in a more proactive and cohesive way. This method contrasts with the traditional approach that applies individual systems and operational improvements independently without consideration of how they can work together to improve operations.

Multiple systems can be integrated through a multijurisdictional, multiagency, or multifunctional system structure. Examples of systems that could be integrated include TMSs that support

surface street operations, freeway operations, transit operations, and others. As more importance is placed on the coordination and management of activities among agencies, especially in dense urban areas, managing the transportation system holistically enhances the ability of agencies to monitor conditions on their facilities and on other agencies' facilities and implement coordinated operational strategies.

The specifics of how an integrated system operates depends primarily on the conditions it faces and existing TMSs and operational strategies. Understanding the users of the facility, corridor, or region—and the unique characteristics of the types of travelers and how they access information—helps determine possible effective operational strategies to deploy in an integrated manner.

Effective multifacility management involves implementing complementary and cohesive strategies, rather than a single strategy along a single corridor, or even a suite of strategies applied to each mode of travel. Agency stakeholders may need to identify potential areas of interconnection between different roadway facilities and modes of travel. Common evaluation methods by each agency stakeholder to assess their systems and integration alternatives are key for selecting operational strategies that support agency operations and in turn help with achieving the shared vision and objectives for the integrated corridor, such as improved travel time, improved system or corridor reliability, or reduced recurring peak-period congestion.

Operational Strategies

Operational strategies are designed to achieve specific goals or objectives that can be clearly identified and measured. When addressing a broader facility, corridor, or region, these goals and objectives may change when compared to operational strategies that serve individual roadways. As such, operational strategies need to be modified to serve multiple goals and procedures. The following potential operational strategies can be addressed:

- Ramp metering.
- Traffic signal control.
- Traveler information.
- TIM.
- Emergency management.
- Special event management.
- Work zone management.
- Information or conditions invoking a decision, action or sharing of information.
- Parking management.
- TSP.
- Road weather management.
- Network surveillance.
- Data management.

Functions

The following functions can be implemented to support the operational strategies noted on the previous page:

- Monitoring roadway conditions.
- Collecting weather information.
- Performing roadway weather maintenance.
- Analyzing collected data.
- Disseminating traveler information.
- Using predictive decision support software to guide operators in system adjustments and overrides.
- Providing traffic detection and surveillance.
- Managing incidents, emergencies, and special events.
- Managing freeway ramps.
- Managing signals.
- Providing priority for transit vehicles at signalized intersections.
- Providing preemption for emergency vehicles at signalized intersections.
- Performing interagency coordination.
- Monitoring and evaluating system performance.

Actions

A set of basic and singular actions that are performed by a person or a TMS component comprise a function. The following actions can be performed:

- Monitoring components.
- Collecting data from detectors, including traffic and roadway conditions data.
- Collecting weather data.
- Sending data to storage.
- Sending data to another system or party.
- Sending data to a TMC.
- Displaying traveler information and public advisories on DMSs.
- Displaying CCTV camera images on a video wall or website.

- Confirming incidents.
- Calling incident response units.
- Calling maintenance crews.
- Changing the ramp meter signal head indication.
- Changing the traffic signal head indication.

Services

Services can support and enhance operational strategies. Services are implemented with the help of communication mediums and mechanisms that facilitate data exchanges between separate systems. The following examples of services can be implemented for operational strategies in an integrated environment:

- A mechanism that facilitates data exchanges between an integrated TMS with a road weather management system to enable rapid response to inclement roadway conditions on surface streets and freeways while improving public advisories. This service can support road weather management, traveler information, and data management operational strategies.
- A cellphone application that enables data exchanges between an integrated TMS and a third-party traveler information provider to provide information on travel times and incidents on integrated corridors. The integrated TMS could comprise subsystems that support freeways and surface streets. This service supports the traveler information, incident management, and data management operational strategies.
- A Web interface that connects to the integrated TMS to inform travelers of available parking spots at a park-and-ride facility and transit arrival times. This service provides travelers with relevant information by leveraging data from the parking subsystem and the transit subsystem, which would usually operate independently, to provide relevant information to travelers in one location. This service supplements the parking management, traveler information, and data management operational strategies.

Systems That Support Freeways

This section discusses the commonly deployed TMSs and subsystems that serve the freeway operating environment. Subsystems encompass a set of physical components that work together to improve the management and operation of the roadway network, optimize performance, and improve safety. In its entirety, the system can carry out operational strategies, functions, actions, and services.

Agency TMSs collect and use traffic data to perform functions, including regulating access to the freeway, monitoring traffic conditions, sharing information with responders to incidents, and providing information on traffic conditions to the public to fulfill operational strategies. The traffic data output collected by the system was a means of achieving agency goals as they pertain to these functions.

As TMSs, subsystems, and components evolved, real-time monitoring and extensive data collection became more common for agencies. Upgrades in physical components and software algorithms allowed subsystems to evolve from implementing reactive and time-of-day strategies to more proactive and predictive ones. The degree of data collection and management capabilities of the subsystems and components dictate the operational strategies and systems an agency decides to deploy.

Emerging technologies improve the capabilities of systems to perform functions and actions to support operational strategies. These technologies also help improve coordination between operations and maintenance agencies. Interagency coordination and communication are important elements that support any strategy. Close working relationships improve responses and productivity, and linked lines of communication enhance system capabilities and mitigation strategies.

Subsystems

Many TMS subsystems are the physical embodiment of the operational strategies they were designed to implement—they were designed to carry out a specific operational strategy (e.g., ramp metering subsystems). Other subsystems were designed to support multiple subsystems and supplement operational strategies (e.g., data management subsystems and CCTV subsystems). The range of subsystems that operate in the freeway environment is vast, but the most common subsystems are provided in the following list:

- Ramp metering.
- CCTV.
- DMS.
- Vehicle detection.
- Traveler information.
- VSL.
- Lane use control.
- Part-time shoulder use.
- Queue warning.
- Road weather information.
- Weigh-in-motion.
- Communication.
- Data management.

Components

Subsystems are made up of individual components that serve a purpose as a part of the subsystem or TMS. The following components serve a purpose as a part of the previous list of common subsystems:

- Ramp meter signal heads.
- Ramp meter controllers.
- ITS controllers.

- Vehicle induction loops.
- CCTV cameras.
- Video walls.
- Workstations.
- DMS boards.
- Lane control signals.
- Radar vehicle detection sensors.
- HAR stations and signs.
- Environmental sensor stations.
- Communication switches.
- Servers.
- Mobile and landline phones.

Agencies use these subsystems and components to implement operational strategies and functions. Current practices for agency TMSs and operational strategies deployed in the freeway environment are described in the next section.

Current Practices in the Freeway Environment

Many agencies have incorporated interesting and advanced approaches to implementing operational strategies using a suite of subsystems to manage the facility and maximize the roadway capacity. A few examples of successful implementation of subsystems and operational strategies by agencies are highlighted in this section. These examples do not represent an exhaustive list of applications and active deployments.

Washington State DOT (WSDOT) implements operational strategies related to traffic incident, traveler information, and freeway management through its TMS.⁽²⁾ The TMS comprises a variety of subsystems to support WSDOT's operational strategies. WSDOT's goals are to reduce collisions associated with congestion and blocked lanes and improve traffic flow through key corridors adjacent to downtown Seattle, WA.

Several subsystems within WSDOT's TMS support these operational strategies:

- Ramp metering.
- VSL.
- Lane use control.
- Queue warning.
- Part-time shoulder use.

WSDOT's TMS and subsystems include the following key components:

- Ramp meter signal heads.
- Ramp meter controllers.
- Vehicle detectors (e.g., inductive loops and radar detectors).
- DMSs.
- Lane use control signs.

By actively managing its TMS and operational strategies, WSDOT improves traffic flow and reduces the likelihood of secondary collisions and panicked braking by dynamically displaying enforceable speed limits on DMSs when congestion is detected downstream.⁽⁶⁾ As shown in figure 8, speed limits are reduced in advance of traffic slowdowns to reduce speed differentials and reduce crashes. Messages are displayed on the overhead- or shoulder-mounted DMS to warn drivers of congestion or collisions downstream with specific lane or distance information. The WSDOT TMS also deploys adaptive ramp metering throughout the Seattle region and dynamic part-time shoulder use along one portion of I-405.



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Figure 8. Photo. Active traffic management (ATM) deployed on I-5 in Seattle.

WSDOT’s success in actively managing these subsystems and operational strategies resulted in reduced speed differentials across lanes, frequency of “stop and go” and abrupt evasive maneuvers, frequency of collisions, collision severity, and increased throughput for approaching onramps.⁽²⁾ Successful implementation also provided some valuable lessons learned—one of which included providing enhanced education on active management strategies and technology, particularly within the managing agency, to increase the potential for the project’s success. Another lesson learned included the importance of procuring durable and high-quality DMSs, which are a foundational component to many subsystems and active management strategies.

Utah DOT (UDOT) manages a TMS that focuses on a road weather management operational strategy.^(2,7) UDOT’s solution provides both operators and motorists with more accurate and timelier road weather and travel impact condition information and forecasts. By providing this information, UDOT is working toward its goals of improved safety and mobility during weather events.

The following subsystems support this operational strategy:

- Traveler information.
- Road weather information.
- Data management.

Several key components comprise these subsystems:

- Road weather sensors and detectors (e.g., environmental sensor stations, radar, cameras).
- DMSs.
- HAR stations.

UDOT initially deployed the pilot Adverse Visibility Information System (ADVISE) on a fog-prone area along I-215 during the 1995–2000 winter seasons to notify motorists of safe travel speeds.⁽²⁾ The warning system was installed on a low-lying, two-mile segment in Salt Lake City, UT, where multivehicle, fog-related crashes occur. Visibility sensors and detection sensors provided data to a subsystem that constantly evaluated the roadway and visibility conditions and traffic volumes. Data were transmitted to a central computer that monitored threats and automatically displayed a warning message and a recommended safe speed on the DMS. The ADVISE system has evolved into the current road weather subsystem that involves meteorologists housed in the TMC to support road weather forecasts.

One of the unique elements of the UDOT TMS is its citizen reporting service.⁽²⁾ Motorist volunteers are enlisted to provide information regarding weather conditions along specific roadway segments through UDOT's own traffic smartphone application. The citizen reporting service supplements UDOT's data subsystem by filling in gaps in existing road condition reports and supporting more timely and accurate forecasts. The service is especially beneficial for UDOT in rural areas that lack adequate road weather data acquisition coverage. The citizen reporting service has proven to be a viable and useful source of road weather information to supplement UDOT's primary data collection methods. One major lesson learned from implementing the citizen reporting service was to provide adequate training and support for citizens who are not experienced in transportation operational strategies to ensure reporting functions smoothly and meets expectations.

The Kansas City Scout (KC Scout) is Kansas City's bi-State TMS, jointly operated and funded by the Kansas DOT and Missouri DOT (MoDOT).^(2,8) KC Scout is used to manage and operate traffic on more than 100 mi of freeway corridor and across State lines in the greater Kansas City metropolitan area. KC Scout encompasses the jurisdictional boundaries of Cass, Clay, and Jackson Counties in Missouri and Johnson County and Wyandotte County in Kansas. KC Scout was designed to decrease congestion, improve rush-hour speeds, increase safety by reducing rush-hour accidents, and improve emergency and incident response. KC Scout is used to implement operational strategies in the freeway environment, including TIM, emergency management, traveler information, special event management, work zone management, and road weather management.

The following subsystems support KC Scout's operational strategies:

- Ramp metering.
- Traveler information.
- Road weather information.
- Data management.

The following key components are used in these subsystems:

- Ramp meter signal heads.
- Ramp meter controllers.
- CCTV cameras.
- DMSs.
- Vehicle detection stations.
- HAR stations.

KC Scout's TMS disseminates information obtained through the subsystems and components to coordinate with public agencies and service providers as they respond to incidents and adverse weather impacting the roadways.^(2,8) All data collected within the network are centrally accessible in the TMC. The TMC accommodates operators, emergency response personnel, and the media for a coordinated approach in implementing operational strategies. By leveraging shared resources and data, KC Scout can provide timely information regarding traffic incidents, scheduled events (e.g., roadway construction), special events (e.g., heavy traffic stadium and concert events), traffic congestion, and road weather information.

A valuable lesson learned from KC Scout is its successful integration of road weather information subsystem with its preexisting traffic management capabilities. By upgrading its TMS, KC Scout was able to integrate weather information into the operator's user interface as another "layer," using data available from external weather information sources, such as the National Oceanic and Atmospheric Administration, the National Weather Service's National Digital Forecast Database, and Meridian-511 providers.^(2,8)

Furthermore, during winter storm events, MoDOT's traffic department operates a workstation for the sole purpose of monitoring road conditions and reporting on the snowplow activity within its coverage area. This information is particularly useful because it can be used to disseminate traveler information in advance, which can help to clear traffic that would otherwise be impeding snowplowing activities. The integration of the weather information subsystem helps KC Scout reach its goals by providing more timely messaging to motorists, thereby improving highway performance and enhancing safety.

The Georgia NaviGator system is a TMS that uses a variety of technologies to monitor, manage, and operate freeway facilities.^(2,9) The Georgia DOT (GDOT) implemented its TMS with the goals of improving traffic flow efficiency, safety, and response times to traffic incidents and disseminating accurate and timely traveler information. To achieve these goals, GDOT uses the NaviGator TMS to implement a variety of operational strategies, including traveler information, ramp metering, TIM, special event management, and work zone management.

The following subsystems are in the Georgia NaviGator TMS:

- Traveler information.
- Ramp metering.
- VSL.
- Traffic signal control.
- Data management.

The following key components comprise the Georgia NaviGator TMS:

- Ramp meter signal heads.
- Ramp meter controllers.
- CCTV cameras.
- Video detection cameras.
- DMSs.

One of the primary goals of the GDOT TMS is to better manage traffic flow. One major TMS function to achieve that goal is to provide real-time traffic information to improve transportation decisions and public information. The TMS collects data through components such as CCTV cameras, video detectors, radar detectors, and a communication subsystem that transmits the data back to the TMC via fiber optic cables. The TMS then enables operators to manage traffic incidents and congestion by controlling ramp meters, traffic signals, and DMS. GDOT uses the collected information to display pretrip and en route traveler information, assist in dispatching incident responders, and provide services to transit agencies to help them manage their operations around changing road conditions.

The data are used to populate a map of real-time traffic and roadway conditions—including travel times, incidents, speeds, and camera views—on GDOT’s website and display messaging on roadside DMSs.⁽⁹⁾

The Georgia NaviGator TMS uses video detection cameras as its primary source of real-time traffic flow information rather than the traditional induction loop or radar detection unit, which makes it a great example for successful implementation using video detection technology as the foundation for traffic management and operations.

The video detection cameras are installed along most major interstates around Atlanta, GA, and can provide continuous speed and volume data, which the TMS uses to generate travel times that can be disseminated to DMSs. However, generating travel time data from video detection components can require significant levels of evaluation and quality control processing compared to more established and traditional detection components such as induction loops. GDOT also uses video detection cameras from different vendors, which can be an additional barrier for data processing.

An example of processing complications includes inconsistent sampling rates (i.e., varying reporting frequencies by component type), which can result in inaccurate aggregation of raw data if an agency assumes consistent sampling rates across components from different vendors. Considerations for agencies implementing subsystems that use video detection components include standardizing the data sampling rate when procuring components or purchasing the same model of components from a single vendor.

Systems That Support Surface Streets

This section examines the commonly used TMSs and subsystems used to implement operational strategies to achieve agency goals and objectives for managing surface streets. Similar to systems that serve the freeway environment, the evolution of physical components and technologies shaped the systems that serve surface street environments.

For nearly 50 yr—from the 1920s until the 1970s—the electromechanical controller was a mainstay in the traffic signal systems market.⁽¹⁰⁾ Cycle lengths were programmed by installing appropriate gears, and the cycle was split into various intervals by inserting pins on a timing dial. As computer technology became more available, microprocessor-based controllers that followed allowed product vendors to add new features simply by changing firmware.

The eventual use of technologies to improve signal operation along arterials then graduated to using a field master controller. This field master controller was located at one intersection and interconnected to nearby traffic signal controllers within the system to allow the operation of the traffic signals at adjoining intersections to be coordinated through telecommunication media (e.g., copper wire, leased phone line with a low-speed modem). When an agency or an operator at a TMC wanted to observe the operating status of a traffic signal controller or to modify control parameters at one or all the traffic signals controlled by the master, a connection was made to the field master, which communicated with local controllers to retrieve data and send it back to the TMC.

As technology continued to improve over time, data collection and communication capabilities also improved. Agencies were realizing the benefits of leveraging data to improve their operations and system performance. As the need for more data increases, agencies are upgrading their data collection and communication subsystems to handle more complex forms of data. For example, newer communication media—such as fiber optic, wireless, and Internet protocol communication systems and video-based detection technologies—have become more widespread, and legacy field master controllers are being phased out.

As agencies integrate traffic signal control systems into the management of the overall surface street network, functions from other systems that were previously operated in a singular, or isolated manner, are being incorporated as a function of multiple subsystems within a region. Regional integration allows agencies to achieve synergy through shared systems and the exchange of data and information. Furthermore, in the absence of central control and monitoring capabilities, systems are isolated, perform independently along a corridor, and cannot be integrated and coordinated with real-time information to achieve agency (or interagency) goals and objectives.

Subsystems

Advanced surface street management strategies and implementation of new and evolving subsystems rely on a strong communications and data subsystem. As communications and data capabilities evolve, so do surface street operational strategies and subsystems. The following common subsystems operate in the surface street environment:

- Traffic signals.
- TSP.
- Emergency vehicle signal priority or preemption.
- Vehicle detection.
- Traveler information.
- DMS.
- CCTV.
- Communication.
- Data management.

Components

With the evolution of detection technology and the range of data that comes with it, signal controllers have evolved to handle the processing needs of the new technology. Surface street systems also have evolved to encompass more than just traffic signal control subsystems and strategies. The following components comprise this growing range of surface street subsystems:

- Traffic signals.
- Traffic signal controllers.
- ITS controllers.
- Vehicle induction loops.
- Wireless local area network (LAN) and wireless technology roadside detectors.
- TSP signal detectors.
- Emergency vehicle preemption detectors.
- DMS boards.
- CCTV cameras.
- Video walls.
- Workstations.
- Communication switches.
- Servers.
- Mobile and landline phones.

The following section discusses current practices of agencies that have successfully deployed TMSs, subsystems, components, and operational strategies that serve the surface street environment.

Current Practices in the Surface Street Environment

The examples that follow illustrate how agencies have deployed TMSs and operational strategies to meet the needs of the agency and support the active management of these systems. The examples are at the forefront of the practice and illustrate either current or future trends.

In California, the San Diego Area Regional Arterial Management System (RAMS) was completed in late 2008 with the primary goal of coordinating traffic signals to optimize traffic flow along interjurisdictional surface street corridors.^(2,11) Before this system was implemented, neighboring agencies in the San Diego region managed their traffic signals, components, and software independently.

The RAMS enabled these neighboring jurisdictions to coordinate traffic signal management activities using common resources. Among the various interjurisdictional traffic signal subsystems, the San Diego RAMS interconnection among the various interjurisdictional traffic signal subsystems is called the San Diego Region Intermodal Transportation Management System (IMTMS).^(2,11) The IMTMS links the subsystems through a regional network composed of both the communications across the subsystems that facilitates shared information and services, as well as the communication between subsystem components and software. With the integration of interjurisdictional subsystems, the RAMS deploys operational strategies, including traveler information, special event management, transit management, traffic signal control.

The following subsystems were deployed to support these operational strategies:

- Traveler information.
- Traffic signal control.
- Transit management.
- Data management.
- Communication.

The following key components comprise these subsystems:

- Traffic signal heads.
- Traffic signal controllers.
- DMSs.
- CCTV cameras.
- Vehicle sensors.
- Regional integrated workstation.

The RAMS consists of multiple subsystems that use a common communication subsystem for integration. This TMS is supported by a traffic signal optimization software package that supports management and interjurisdictional signal coordination efforts.⁽¹¹⁾ The traffic signal optimization software was installed at participating agency facilities, where operators coordinate signal changes through a map-based user interface on a regional integrated workstation. This TMS allows agencies to view signals from neighboring agencies, including signal status, controlled time, and timing and coordination information, and implement regional timing plans for both their own signals and preselected signals from neighboring agencies.

Additionally, the RAMS supports shared functions among the stakeholder agencies such as interjurisdictional signal timing, regional timing plan implementation, field component control management, incident and event management, and resource management. Agencies can set the amount of information and control shared.

The RAMS is a complex TMS that encountered numerous delays during project deployment. These delays could primarily be attributed to disagreements among partners that led to difficulty moving from planning to deployment, the lack of alternative support for the software system, and numerous changes in project managers that required refamiliarization with the project. Based on this project, lessons learned that could be applied to other integration projects include an adoption of project management standards, with a structured deliverable document review process; proper workload adjustments for public agency staff responsible for technology project management; and allocation of time for project managers to attain technical expertise regarding the system, procedure development, policy formation, and involvement of operations staff throughout the planning and design phases of the project.

The Seattle DOT (SDOT) manages an ITS-based TMS that serves the surface street environment in the Seattle metropolitan area.^(2,12) The goal of this TMS is to improve multimodal travel in terms of safety and efficiency. To accomplish these goals, SDOT leverages ITS and technology to enhance its TMS and implement operational strategies. These operational strategies include traffic signal control, traveler information, TIM, work zone management, special event management, and traffic signal priority.

The following subsystems comprise the TMS and support SDOT's operational strategies:

- Traveler information.
- Traffic signal control.
- TSP.
- Data management.

These subsystems include the following key components:

- CCTV cameras.
- DMSs.
- Traffic signal heads.
- Traffic signal controllers.
- TSP detectors.
- Vehicle induction loop detectors.
- Wireless LAN detectors.
- Bicycle induction loop detectors.
- Video wall.

In 2014, SDOT became an early adopter of integrating wireless LAN detectors into its traveler information and data management subsystems to measure travel times on congested corridors in the city.⁽²⁾ SDOT also uses these detectors to support its TIM operational strategy. By detecting anomalies in travel times, operators can verify incidents using CCTV cameras and respond to them in a timelier manner. Additionally, these wireless LAN detectors also are used to support

the traveler information operational strategy by providing real-time travel time data to the traveling public on DMSs and the public travelers' website.⁽¹²⁾

SDOT's implementation of detectors into its TMS is a great example of leveraging emerging technology to support operations in the surface street environment. Before the wireless LAN detectors were installed, SDOT relied on license plate readers to collect travel time data. However, license plate readers were expensive to procure and maintain and raised privacy concerns regarding collecting plate information that could be traced back to personal driver information. Wireless LAN detectors do not have the same issues; they are cheaper to procure and maintain, and data collected from mobile devices are securely encrypted and anonymized. As data collection continues to increase across the transportation world, issues such as data privacy and data security become an important factor in the type of subsystems and components agencies decide to deploy. A lesson learned from SDOT's example is to consider the emerging issues that accompany improved technology when planning to deploy these subsystems and components.

The City of Fort Worth, TX, manages a TMS in the surface street environment that has goals related to reducing congestion, improving air quality, improving safety, and moving traffic.^(2,14) To make progress toward these goals, the City of Fort Worth implemented operational strategies such as traffic signal control, traveler information, TSP, emergency management, and road weather management.

The following subsystems were deployed to address these operational strategies:

- Traveler information.
- Traffic signal control.
- Flood warning/road weather information.
- Data management.

These subsystems include the following key components:

- Traffic signal heads.
- Traffic signal controllers.
- Vehicle detectors.
- Bicycle detectors.
- TSP detectors.
- High-water flashing beacons.
- Road weather detectors (weather stations).

One of the subsystems managed by the City of Fort Worth that stands out is the flood warning subsystem.^(2,13) The high-water warning subsystem relies on data collected from rain and water level gauges at low-water crossings and weather stations. Data collected from these weather stations are transmitted to the subsystem in realtime to determine whether the allowable threshold has been breached. When a breach occurs, the subsystem activates roadside flashing beacons with static signage to immediately warn drivers of a flood hazard. In addition to activating these components, alerts are simultaneously sent to first responders and incorporated into travel condition information that is made available to the public.

The flood warning subsystem relies on the communication subsystem to transmit the data to the data management subsystem. Flood warning messages are pushed out to other agency stakeholders, social media platforms, and the media. Flood warning information also is made available on the City of Fort Worth’s website with interactive filters and graphical displays related to a wide range of data metrics (e.g., rainfall amounts, hail intensity, dew points, reservoir storage status, flood status, flashing beacon status, gate position, and many others).

Systems That Support Facilities, Corridors, or Regions

This section discusses the commonly used TMSs and subsystems that enable operational strategies in multiple environments such as facilities, corridors, or regional environments. Multiple systems can be integrated by using a variety of operational models such as multijurisdictional and multiagency. Examples of systems that can be integrated include TMSs that support surface street operations, freeway operations, transit operations, and others. As more importance is placed on interagency coordination—especially in dense urban areas—managing corridors in an integrated manner provides benefits such as shared resources, more efficient communications, faster response times, and saved costs.

The specifics of how the integrated system operates depend primarily on the conditions faced and existing TMSs and operational strategies. Understanding the users of the facility, corridor, or region—and the unique characteristics of the types of travelers and how they access information—helps determine operational strategies that may be effectively deployed in an integrated manner.

Effective regional or corridor management involves implementing multiple complementary and cohesive strategies rather than a single strategy along the corridor, or even a suite of strategies, applied to different modes of travel. Agency stakeholders need to identify potential areas of interconnection between different roadway facilities and modes of travel. Common evaluation methods by each agency stakeholder to assess their systems and integration alternatives are key for selecting operational strategies that support agency operations and in turn help with achieving the shared vision and objectives for the integrated corridor, such as improved travel time, improved system and corridor reliability, or reduced recurring peak-period congestion.

Subsystems

Advanced operational strategies and the implementation of new and evolving subsystems rely on a strong communications subsystem, which also supports and facilitates data and information sharing among agencies. These functions give the agency a capability that it might not have previously had, such as the ability to monitor regional traffic conditions and coordinate effective regional response plans, including disseminating traveler information for planned and unplanned events that span both freeway and surface street environments. These coordinated systems improve operations, safety, and travel time reliability while using resources more efficiently. The following examples of potential subsystems could be applied to facilities, corridors, or regions:

- Ramp metering.
- Traffic signal.
- Traveler information.

- Vehicle detection.
- Lane use control.
- Queue warning.
- TIM.
- TSP.
- Emergency vehicle signal priority or preemption.
- Road weather information.
- CCTV.
- Communication.
- Data management.

Components

Subsystems comprise individual components that serve a purpose as a part of the subsystem or TMS. The following components serve a purpose as a part of the previous list of subsystems:

- Ramp meter signal heads.
- Ramp meter controllers.
- Traffic signals.
- Traffic signal controllers.
- ITS controllers.
- Vehicle induction loops.
- Wireless LAN and wireless technology roadside detectors.
- TSP signal detectors.
- Emergency vehicle preemption detectors.
- CCTV cameras.
- Video walls.
- Workstations.
- DMS boards.
- Radar vehicle detection sensors.
- Environmental sensor stations.
- Communication switches.
- Servers.
- Mobile and landline phones.
- Fiber optic networks.

Current Practices in Facility, Corridor, or Regional Environment

The examples presented in this section illustrate successful agency deployment of TMSs and subsystems that provide a multimodal, multifacility, and multijurisdictional set of operational strategies. The Dallas, TX, U.S. 75 Integrated Corridor Management System was designed to achieve the goals of increasing corridor throughput, improving travel time reliability, improving incident management, and enabling intermodal travel decisions.^(2,14) The Dallas Area Rapid Transit (DART) is leading this TMS, which provides participating agencies with an integrated platform for managing traffic, incidents, and construction within the corridor. Participating

agencies in addition to DART include the City of Dallas, City of Richardson, City of Plano, Town of Highland Park, City of University Park, North Central Texas Council of Governments, North Texas Tollway Authority, and Texas DOT (TxDOT). Subsystems from participating agencies are interconnected in this TMS to facilitate data sharing, communication, and operational strategies.

Operational strategies were selected and broken out by network type, including TSP, TIM, special event management, managed lanes, traveler information, traffic signal control, parking management, ramp metering, and data management.

The following subsystems were integrated to implement these operational strategies:

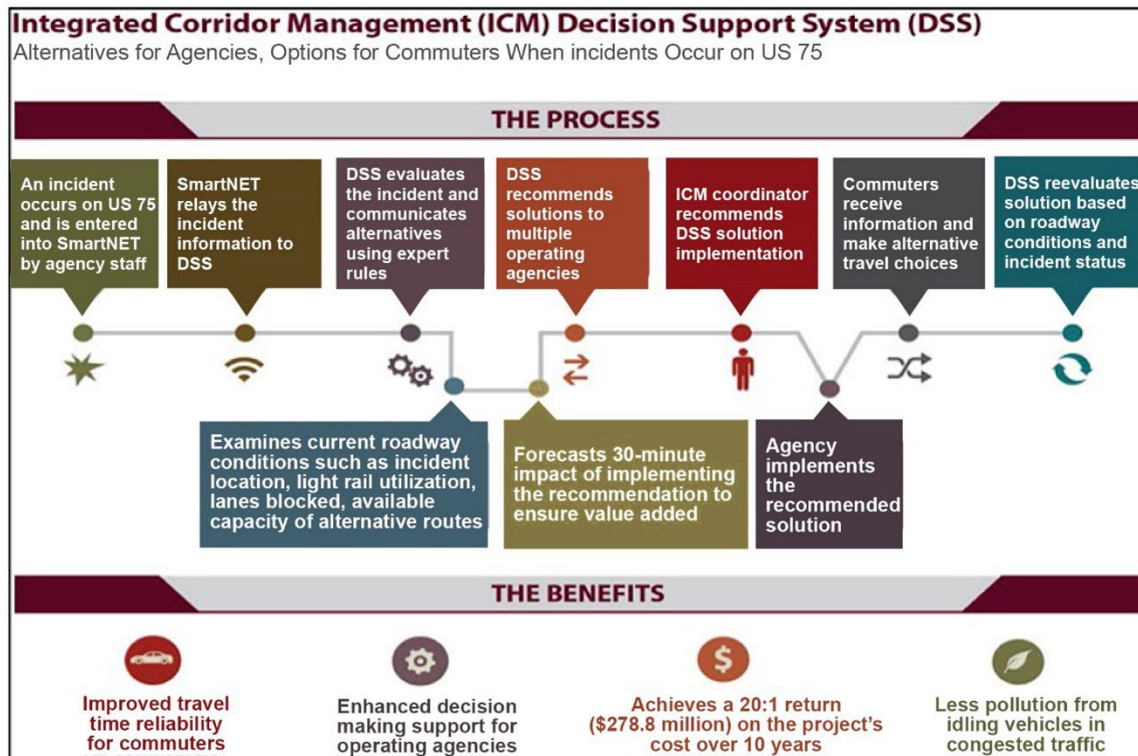
- TSP.
- Traveler information.
- Transit management.
- Decision support.
- Data management.

This TMS includes the following key components:

- Traffic signal heads.
- Traffic signal controllers.
- Ramp meter signal heads.
- Ramp meter controllers.
- TSP signal detectors.
- CCTV cameras.
- DMSs.
- Vehicle detectors.
- Smart parking detectors.

The U.S. 75 TMS integrates multiple subsystems that support sharing internal and external incident, construction, special event, transit, and traffic data. The TMS uses a decision support subsystem to provide operational planning and evaluation data through a center-to-center interface that communicates to various agency systems. The decision support subsystem also is used to facilitate operational strategies. The TMS uses a Web-based graphical user interface called SmartNET that allows agency subsystems and centers to share important information, such as location and status of incidents, resources deployed, planned events, and construction areas.⁽¹⁴⁾ The TMS also uses SmartFusion to manage the data from the various subsystems and share these data with external parties through their 511-traveler information subsystem.

The daily operation of the corridor is an expansion of the existing relationships and operations of the stakeholder agencies in the region, but with additional coordination, communication, and responses. All operations through the corridor are coordinated through the decision support subsystem. Figure 9 illustrates the interactions of the functions and processes of the U.S. 75 system in Dallas.



Source: FHWA.

Figure 9. Diagram. U.S. 75 ICM decision support in Dallas.⁽¹⁴⁾

U.S. 75 is good example of a TMS that serves an integrated corridor. This TMS fundamentally changed how transportation agencies in the U.S. 75 corridor collaborated to move people and vehicles through the corridor and implemented coordinated operational strategies such as TIM and traveler information. TMSs and operational strategies that serve the integrated corridor environment are fundamentally focused on interagency coordination. As such, the lessons learned from the deployment of the U.S. 75 TMS also are focused on interagency coordination.

Participating agencies confirmed that integrated approaches to TMSs and operational strategies build on existing institutional arrangements because these arrangements are the key to building consensus. Institutional issues that may arise in the early parts of the project may be mitigated by setting expectations and defining roles and responsibilities.

Furthermore, the key to integrated corridor TMS operations success is data sharing. Planning for the system in the short time is important, but it also is imperative to plan for future expansion. Other considerations include the geographic region, the systems and agencies involved, and the applications that may be needed in the future. One way to ensure these issues are addressed is to include the integrated corridor TMS in the regional ITS strategic plan, so that agencies are committed to its deployment in the region.

The San Diego, CA, I-15 Corridor TMS is led by the San Diego Association of Governments.^(2,15) Major stakeholders involved in the development and operations of the TMS include the California DOT (Caltrans), California Highway Patrol, Metropolitan Transit System, North County Transit District, City of San Diego, City of Poway, and City of Escondido.

The goals of the San Diego integrated corridor TMS are to grow multimodal travel, improve safety, provide traveler information, provide integrated approaches to problems, and manage the corridor holistically. To achieve these goals, operational strategies are implemented in coordinated and integrated ways. These strategies include ramp metering, traffic signal control, TSP, traveler information, TIM, priced managed lanes, multimodal electronic payment, and data management.

The following subsystems in the I–15 TMS support these operational strategies:

- Traffic signal control.
- TSP.
- Ramp metering.
- Traveler information.
- Decision support.
- Data management.

These subsystems include the following key components:

- Traffic signal heads.
- Traffic signal controllers.
- Ramp meter signal heads.
- Ramp meter controllers.
- CCTV cameras.
- Vehicle detectors.
- DMSs.
- TSP detectors.
- Electronic toll collectors.

The operational strategies of the integrated corridor and critical coordination among agencies are accomplished through a Virtual Corridor Traffic Management Center (VCTMC) that manages the ICM system and infrastructure.⁽²⁾ The VCTMC allows further integration of the agency subsystems and functions. By integrating subsystems, participating agencies can provide seamless traveler information, such as travel times, incident information, and expected delays through DMSs, the 511 mobile phone application, and other sources.

Like the DART system, the CA I–15 Corridor TMS also integrates a decision support subsystem that uses real-time simulation, predictive algorithms, and analysis to evaluate potential congestion mitigation strategies and suggest an optimal combination of those strategies for the corridor.⁽¹⁵⁾ The coordinated effort also resulted in improved joint agency action plans for traveler information, traffic signal timing, ramp metering, and managed lanes. The integrated subsystems also enhanced management across the different facilities, including shared control and coordination across jurisdictions for field components.

The successful deployment of the I–15 integrated corridor TMS encourages agencies to manage their transportation corridors as integrated and multimodal systems rather than as individual systems. The use of analysis, modeling, simulation, and performance measures to make informed

decisions and shape operational strategies is a large factor in the success of the I-15 TMS. Success also was enhanced by interagency coordination and an interagency decision support subsystem. Agencies should consider all these items when planning and designing an integrated corridor system.

The City of Houston, TX, is home to the Houston TranStar TMS, which is a unique partnership of four agencies: the City of Houston, Harris County, the Metropolitan Transit Authority of Harris County, and TxDOT.^(2,16) The goal of this TMS is to keep motorists informed, roadways clear, and lives safe within the Houston metropolitan area.

The TranStar TMC houses representatives from the participating agencies, which enables the resources to be shared and information exchanged in one physical location. The collaborative nature of this TMS provides an integrated approach to implementing operational strategies. Some of the operational strategies implemented by TranStar include traffic signal control, ramp metering, TIM, emergency management, traveler information, road weather management, work zone management, and data management that are applied to both freeways and surface streets.

The following subsystems comprise the TranStar TMS:

- Traveler information.
- Ramp metering.
- Traffic control signal.
- Regional incident management.
- Emergency management.
- Transit management.
- Automated flood warning and road weather information.
- Data management.

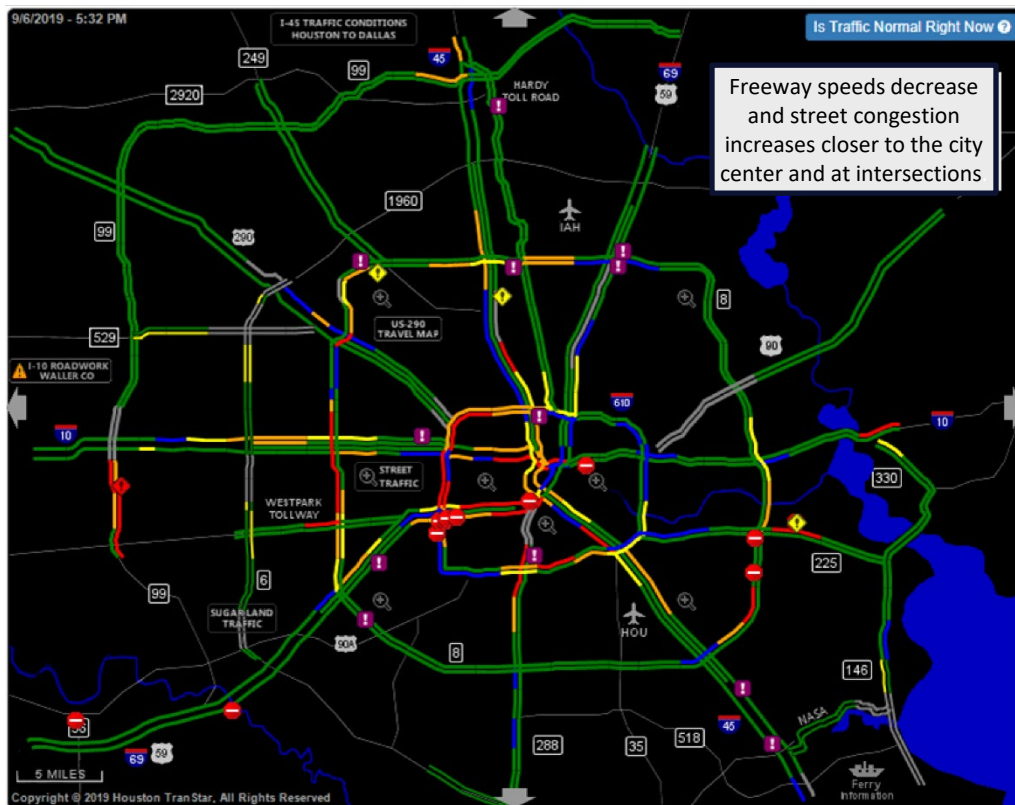
The TranStar subsystems include the following key components:

- Traffic signal heads.
- Traffic signal controllers.
- Ramp meter heads.
- Ramp meter controllers.
- CCTV cameras.
- DMSs.
- HAR stations.
- Road weather detectors.
- Vehicle detectors (e.g., inductive loops, radar, video, wireless technology).

This collocation of agencies and technologies allows subsystems and components to be pooled, which provides familiarity among the participating personnel for effective operational strategy implementation. For example, agencies have shared access to the CCTV cameras and DMSs for effective incident management and traveler information dissemination across different operating environments.

This integrated TMS also enables operations staff to effectively dispatch vehicles to remove debris and communicate with emergency vehicles about the most direct routes to an incident where the route may include both freeways and surface streets.

TranStar can inform travelers of conditions using its real-time traffic map and posting traffic alerts to its social media account. Additionally, Houston experiences many heavy rainfall events, making flooding a concern for travelers in the region.^(2,17) TranStar leverages Harris County's flood control district warning subsystem to alert travelers where flooding may be a risk during heavy rain events. Figure 10 provides a snapshot of the Houston TranStar website, which shows vital travel information, including flood warning indications, travel times, and incidents.⁽¹⁶⁾



© 2020 Houston TranStar.

Figure 10. Screenshot. Houston TranStar traffic map (2020).⁽¹⁶⁾

TranStar was one of the first TMSs to integrate transportation and emergency management in the United States.⁽²⁾ The emergency operations center located in the same building as the transportation operations center (TOC) is where Harris County takes the lead role in emergency response. Harris County is responsible for improving public safety during human-made and natural disasters. Depending on the disaster, coordination efforts also may include the U.S. Army, Salvation Army, Harris County Toll Road Authority, amateur radio operator volunteers, the American Red Cross, and local governments. The automated flood warning subsystem, Doppler radar imagery, satellite weather maps, road flood warning systems, and the Regional Incident Management System are some of the tools used during emergency response.

TranStar is a great example of a TMS that operates within an integrated corridor that also is multimodal, multifacility, and multijurisdictional.

WHAT IS THE NEXTGEN OF TMSs?

The NextGen of TMSs emphasizes the exponential increase in the availability, collection methods, and sources of data. New technology has allowed data to be harvested from various mediums, including newly emerging automated or connected vehicles. What differentiates the NextGen TMSs from legacy TMSs is that traffic performance, traffic safety, and system functionality are no longer restricted to historical data; they can incorporate real-time expansive data in more ways than ever before. NextGen TMSs may provide new capabilities and functions or may simply modernize existing systems because of technology changes. NextGen TMSs also may provide a platform where new features and functions are more easily integrated with existing TMS functions in the future. A TMS is the software and supporting technology as well as the staff actions and business processes that the software supports.

NextGen TMSs are based on software, databases, and information technology (IT). The following issues are considered in deploying NextGen TMSs:

- Software tools may be unsupported, past end-of-life, or require specific versions of software libraries or operating systems.
- Interfaces may be difficult to expand or enhance.
- Storage formats may be unsupported or require translation to modern formats.
- Applications and data may not be easily shared across networks.
- Applications may have security vulnerabilities or use outdated components that do not comply with agency IT policies.
- Only certain staff members may be responsible for, or be knowledgeable about, operation and maintenance of the application.
- Field devices may use custom protocols.
- Support documentation for protocols or configuration of field devices may be unavailable.
- Older management applications may not support newer field device protocols or data exchange formats.
- Field devices may use specialized hardware that cannot be repaired due to lack of spare parts or replacement boards.
- Communication links (serial, dial-up) may not support high-speed or high-bandwidth data exchanges.

- Field device command and control may be siloed in multiple applications with multiple databases and interface formats.
- Operational strategies may be hard coded or difficult to configure or change.
- The NextGen TMSs may need to transition from the existing legacy methods to methods anticipated in the future.

ASSESSING THE CAPABILITIES AND NEEDS FOR IMPROVEMENT

This section discusses how agencies examine the need for a new, or modification of an existing, TMS. It discusses the process, issues to consider, and practices for planning and developing a new, replacement TMS, or specific improvements (e.g., software platform, data platform, telecommunication media) for a TMS. Assessing the capabilities and performance of the TMS include a combination of qualitative and quantitative information. Agencies then report notable trends in the data using emerging technologies and visualization methods. This information allows agencies to make informed decisions to improve and enhance system performance, and it identifies any issues resulting in inefficient system performance. Once agencies properly assess their systems and determine their needs for improvement, agencies can incorporate the identified improvements into a ConOps. Improving a TMS may require using the existing ConOps and supporting information. The development and planning of a ConOps is discussed in detail in chapter 6 of this report.

Effective Practices for Capability Assessments

According to the *Handbook for Developing a TMC Operations Manual*, agencies that are proficient in their performance measurement process generally perform the steps outlined in the following list.⁽¹⁸⁾ (Note: This process is an iterative one that agencies need to refine to best suit their needs):

1. Identify the critical activity.
2. Identify the goals and objectives of the activity.
3. Identify and develop a set of performance measures that relate to the goals and objectives.
4. Establish performance targets that meet those goals and objectives.
5. Identify the uses of the performance measures and the audience of those measures.
6. Identify the data needed to calculate the performance measures, including the analytical tools required.
7. Establish the data collection and evaluation procedures.
8. Establish procedures for ensuring data collection methods produce “good data.”

9. Evaluate the performance measures in comparison to the performance targets.
10. Determine corrective actions or progress needed to achieve the targets.
11. Determine performance metrics reporting or presentation formats.

The measures and metrics are at the center of this process. An agency can select from thousands of potential measures that their TMS can use to assess performance. Agencies select the measures that can effectively gauge the progress toward their goals based on their current resources. If the identified measures can assess current progress well, but the agency does not have the capacity to continuously collect and analyze the data, the measures are not effective. A good measure should typically have four main traits:

- Be realistic with respect to the capacity and resources of the agency. Required data that are expensive to collect and analyze means the measure is likely to be unsuccessful.
- Measure the correct item, such that it focuses on defined goals and objectives set by the agency. Performance measures also can apply to areas outside operations.
- Be mindful of the presentation of the information to ultimately be simple, understandable, and meaningful to the customer. Changing the measure to be more tailored toward different audiences may be more effective.
- Be responsive to changing conditions. A performance measure that does not accurately capture events or major changes cannot adequately show progress toward goals.

Initial activities for agencies to consider when planning a new TMS, or improving, upgrading, or replacing an existing TMS, include conducting feasibility studies either for the system or for specific components. Feasibility studies include the following steps:

- Recognizing that improving, revising, replacing, or planning a new system could apply to any system component and does not necessarily mean that the entire system be enhanced at once. A feasibility study can be conducted on an entire system or just the proposed enhancements or expansion of the existing system. Agencies may elect not to deploy an entire new system due to constraints such as lack of resources, or they may elect to pilot a new function along a specific corridor, road facility, or district. Recognizing that specific components of a TMS can be enhanced to gain adequate benefits allows an agency to make incremental improvements at a feasible pace.
- When implementing a TMS, or updating specific components of a TMS, many elements can be considered as part of the feasibility study. A feasibility study may evolve from engagements with agencies, industries, or literature scans. Major elements include budgeting for the effort and planning for interoperability with existing systems. Updating specific aspects of a TMS could include replacing or updating software platforms, computing platforms, data subsystems, user interfaces, and field components; expanding areas of service; enhancing the operational strategies, services, or functions of the system;

and other possibilities. Agencies should consider the requirements to implement these changes in the feasibility study.

- When an agency wants to enhance or expand its current TMS operational strategies or functions or implement a new TMS, the project becomes part of a planning process. A feasibility study or assessment is completed as part of, or in parallel with, the planning process and completed before agencies move forward with the development of the TMS concept. The study or assessment includes examining the risks associated with performing these enhancements and improvements, meeting with various stakeholders to fully understand needs, and outlining a rough system design to identify challenges and proposed benefits. Considering the rapid pace of technology advancements and the associated impacts on TMSs, understanding what factors drive the risk and feasibility of a TMS project and how they may change in the future is imperative.

Current Practices for Capability Assessments

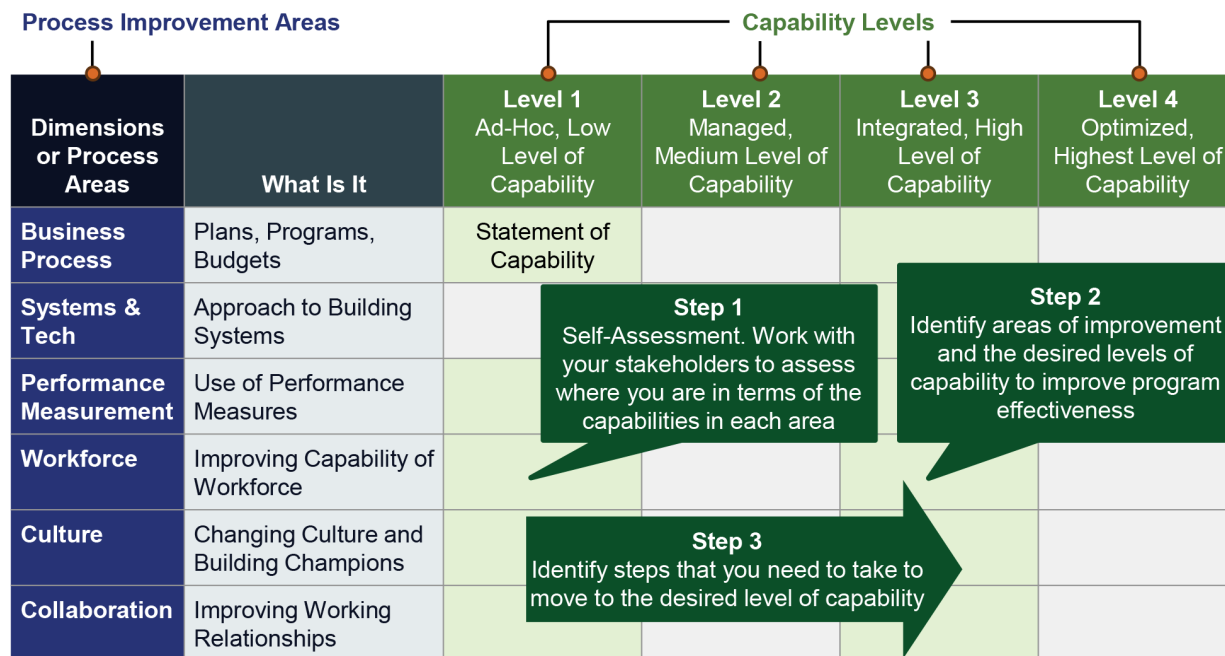
Several effective practices should be considered when attempting to make capability assessments. Agencies are often faced with several issues to consider while assessing the current capabilities or future enhancements for a TMS. An example of a key issue to build off and consider is combating congestion-related issues. Planning TMS to address current needs and future functions within the context of addressing congestion issues as part of a congestion management plan can help focus the strategic planning of a TMS. Agencies that consider the goals, objectives, and operational strategies developed as part of the congestion management plan, which targets improving systemwide performance and reliability, could gain more effective allocation of limited transportation funding to apply toward a TMS plan that is integrated with broader agency and regional plans.

The integration of TMS planning also can be included as part of a metropolitan transportation plan (MTP) and TIP for an MPO or as part of a TSMO plan. Integrated planning processes might require a slightly different focus and level of detail to describe the influence of the TMS to enable the wide range of operational strategies and services that the TMS is expected to support. In some cases, only a description of the TMS may be needed—listing its capabilities, noting the operational strategies that would be provided, and identifying the resources needed over a planning horizon to enable the TMS to operate in that environment. By providing this planning information within an integrated plan, support placeholders can be identified early to ensure an effective TMS implementation, including any necessary operations staff and funding needed to move forward.

As transportation issues continue to arise, the importance of addressing these issues at the institutional and programmatic level has emerged. Tools are available to help agencies address these issues and assess their readiness to make improvements. Common examples of these tools include the capability maturity model (CMM) process and the capability maturity framework (CMF) tool—both of which are frequently used in the planning process to help agencies assess their capability to deploy TMSs at a more formal and programmatic level.^(19,20)

Transportation agencies adopted the CMM, illustrated in figure 11, as a process to increase the effectiveness of TSMO at the programmatic level as determined by the second Strategic Highway Research Program (SHRP2) 2017 annual report.^(21,22) Based on the CMM approach, the

CMF tool was developed to assist transportation agencies as they self-evaluate their organizations' current transportation operations and management processes with respect to specific operational strategies or bundles of strategies. The CMM process and the CMF tool can be used to assess an agency's current TMS operations and identify areas of improvement with respect to program effectiveness.



Source: FHWA.

Figure 11. Diagram. CMF process overview.⁽²¹⁾

Additionally, the CMM and CMF can help guide the development of institutional architectures into a more formal program to support TMSs. The CMM and CMF can be used to help agencies address the nontechnological challenges in developing a program centered on actively managed TMSs and help with the adoption of these systems. This process is valuable during the planning and assessment stages of identifying future needs. Agencies can embark on the usually longer term process of ensuring they have adequate resources available to make the identified improvements, assuming their prioritization deems it necessary to deliver the performance and capabilities needed for the areas the TMS is expected to actively manage.

In addition to the existing CMF tools, FHWA also has self-assessment resources for specific TSMO program areas or strategies.⁽²¹⁾ TMS capabilities can be fundamental to many different agency operations, and while self-assessments are common for many other aspects of agency operations, information to assist with assessing TMSs and information regarding issues to consider is lacking. Table 1 includes some areas to consider when assessing day-to-day staffing-related and policy-related TMS capabilities. The unique part about assessing TMSs is that resources currently do not exist to support assessing and benchmarking performance. Planning, design, development, and implantation of TMS and NextGen of TMS improvements are some issues to consider. Another consideration taken is the inclusion of TMS plans, requirements, and resources into agency or TSMO policies programs, plans, initiatives, services,

or efforts. Additionally, some more of the gaps or inefficiencies in the current TMS Capabilities assessment process are listed in table 1.

Table 1. Issues to consider when assessing TMS capabilities.

| Capabilities | What to Consider |
|---------------------------------|--|
| Day to day | <ul style="list-style-type: none"> • Maintenance, repairs, and asset organization. • Operation (e.g., TMC, performance (e.g., monitoring, evaluation, and reporting), and active management). • IT, security, emergencies, and support other systems (e.g., remote operations). |
| Staffing TMSs | Plans, policies, resources, scheduling, and contractors. |
| Policies, procedures, and tools | Support managing and operating TMS. |

Using Modeling and Analysis Tools

Modeling and analysis tools can be used during the planning phases of developing a TMS to provide insights into the mobility impacts of different approaches. Planners use a variety of modeling tools to simulate various TMSs and operational strategies. These tools can be categorized as microscopic, mesoscopic, or macroscopic. The appropriate modeling tool depends on the type of TMS and the scale of impacts desired to be simulated.

Although challenges, gaps, and issues exist in linking planning and operations using analysis tools and methods, opportunities are available to use the existing tools in a more innovative manner to help simulate different types of TMSs. Safety and environmental impacts and benefit–cost analyses are all considerations for planning a TMS that typical traffic modeling tools may not incorporate in a straightforward manner. Safety analysis can be completed by using crash and incident data. However, crash reports and incident data typically lack location-specific information with enough fidelity to be useful for evaluating many TMSs, making safety analysis a challenging task. The environmental impacts of a TMS can be assessed by using the U.S. Environmental Protection Agency’s (EPA) emissions rate software Mobile Source Emissions Model (MOBILE) or other models such as the MOtor Vehicle Emission Simulator (MOVES).⁽²³⁾ Conducting a benefit–cost analysis allows an agency to consider the financial perspective of implementing a TMS.

FHWA has developed the Tool for Operations Benefit-Cost Analysis (TOPS-BC) to help users estimate the costs and benefits of implementing various TSMO strategies, including the operational strategies deployed by TMSs.⁽²⁴⁾ The BCA.Net is a browser-based benefit–cost analysis tool that uses FHWA’s Highway Project Benefit-Cost Analysis System.⁽²⁵⁾ The FHWA Traffic Analysis Toolbox provides additional guidance on analysis methods to help agencies select the most appropriate tools for their planning needs in analyzing various TMS-deployed operational strategies, such as ramp metering, traffic signal coordination, and TIM.⁽²⁶⁾

Other high-level issues to be considered when planning for a TMS are institutional policies and regulations and the feasibility of increasing operations personnel. Identifying and resolving these

issues before taking the next step toward designing a system is important. The stakeholder engagement activities around the preparation of the ConOps document during systems engineering may be the appropriate place to identify these issues and reach consensus on any future challenges that may arise in implementing the TMSs. As outlined by FHWA, TSMO is the use of strategies, technologies, mobility services, and programs to optimize the safety, mobility, and reliability of the existing and planned transportation system.⁽²⁷⁾ TSMO strategies offer effective ways to improve transportation system performance in a quicker and more cost effective way. The following case study inset provides an example of incorporating TSMO when considering a ConOps and performing a feasibility assessment on a system that builds on the current capabilities and identified needs.⁽²⁸⁾

Effective Practice: Feasibility Assessment

In 2011, the New Mexico DOT (NMDOT) performed a feasibility and cost assessment for an Albuquerque MPA Joint Traffic Management Center (JTMC).⁽²⁸⁾ The JTMC would be shared by staff from the City of Albuquerque, Bernalillo County, and State agencies that have transportation operations responsibilities. The following process is an example of how a TSMO can be followed within a transportation management system.

NMDOT's primary purposes for conducting the assessment were to determine the feasibility of implementing a joint TMC, or JTMC, and the costs associated with that implementation. The assessment identified requirements for the JTMC (including staff, facility, and site requirements); site and building constraints; potential site and building opportunities for both immediate move-in and future growth of the JTMC; security analysis; potential near-term and long-term enhancements to the site and building for transportation operations; and costs. The assessment effort also included an analysis of the ConOps that describes the planned operations for the JTMC.

NMDOT developed the requirements for the JTMC using participating agency input for the near-term implementation period and 10 yr and beyond. The agency performed an examination of the existing site and building conditions to determine any challenges to developing a JTMC and where opportunities for enhancements would be made. NMDOT planned the JTMC to be operational 24 h a day, 7 d a week with both transportation management and emergency event public safety communications functions. Due to the nature of the JTMC, security was a major item of emphasis in the feasibility assessment efforts. The agency developed a security strategy for the JTMC that identified various security components required to ensure uninterrupted operations. The security component requirements included items such as access card readers, security cameras, bullet/impact resistance building components, alarms, backup power, information security, motion detectors, and others. A major component of the feasibility assessment was the program level cost estimate performed. The rough order of magnitude cost estimate for the proposed JTMC provided budgetary information needed to determine the feasibility of developing the new facility and maintaining operations. Elements factored into the cost estimate included construction costs, contractor fees, building components, electrical components, design costs, and others.

The feasibility study provided the participating agencies with assurance that the JTMC implementation was possible and reasonable. This feasibility study allowed the agencies to proceed with a more detailed needs-assessment study, schematic design efforts, and the development of more detailed budget allocations and phasing plans.

CHALLENGES AND CONSTRAINTS

Transportation agencies are faced with unique challenges that affect how they implement TMSs or improve operational strategies. These challenges likely vary based on the level of maturity of the existing system. Identifying challenges is an important evaluation metric and starting point for an agency to implement improvements. Although organizational issues require a top-down commitment to change, an agency needs to evaluate several technical and operational challenges in its pursuit toward enhancing or improving its TMS. Recently, the philosophy has shifted from a design and construct ideology to a more formal and programmatic approach to efficient and proactive operation of facilities. “Active management” and TSMO are growing concepts that align with this shift in philosophy. As outlined by FHWA, TSMO involves implementing a set of strategies that improve an agency’s existing transportation system performance without major capacity expansion and operating the available transportation assets at a high rate of efficiency.⁽²⁷⁾ This guided methodology directly links to how a transportation agency can solve problems and create a “way of doing business” to create an optimally performing and effective transportation management system.

The following challenges and best strategies for improving TMSs could be examined:

- **Emphasis has traditionally been on capacity expansion instead of efficiency improvement.** The strategies to overcome this challenge require developing a multiyear strategic plan for the system and integrating it into agency plans, using an ITS strategic plan as a roadmap for the research, development, and adaptation of technology-based transportation systems. In addition, the plan acts as a guide for investing in the TMS technology- and operations-focused solutions. Furthermore, interested stakeholders can be informed about the benefits of implementing the system. Integrating multiyear plans or feasibility plans into these planning processes ensures consistency at various planning levels and helps to elevate the TMS implementation. The agency assesses and reports on legacy TMS capabilities to benchmark planned capabilities in 5 or 10 yr. Another strategy would be to move away from the design and construction philosophy by implementing a TMS that can help shift focus toward operations, which would require defining operational benefits in a way that is meaningful and easy to understand for TMS managers, staff, operators, and policymakers.
- **Lack of understanding of TMS objectives from elected officials and decisionmakers.** The main strategy to overcome this challenge is to coordinate with other agencies and political entities around technical resources. Additionally, this strategy requires consulting legal entities and enabling legislation as well as forming formal agreements with enforcement agencies.

- **Lack of coordination between multiple stakeholders.** The key to closing the communication gap between multiple stakeholders is to set up communication protocols and ongoing coordination. The protocols include methods to involve and retain nontraditional partners by focusing on common issues and building initial successes. Additionally, a focus on encouraging ongoing cooperation around events and activities is helpful in creating a more inclusive outreach. These strategies also include transportation agency presence in existing or new public safety forums (e.g., governor’s office of emergency management). Ultimately, this coordination establishes multiagency committees at multiple working levels.
- **Lack of funding and resource constraints.** To combat lack of funding, an agency can pursue innovative funding mechanisms and prioritize operations in planning. Integrating the managing condition of TMS assets into the assessment of TMS capabilities and planning for future improvements can provide a better sense of long-term resource needs. Innovative funding mechanisms or other sources of funding to be pursued include new user taxes, dedicated local sales taxes, toll revenues, or economic development funds. In addition, establishing relationships with policy decisionmakers and legislators to benefit from earmarked funds and encourage resource sharing from other departments is important. TMS improvements and operations-focused projects are included in agency’s planning documents. Finally, an agency develops plans for meeting future staffing needs that evolve with the desired capabilities of the TMS.
- **Rapidly changing technology requires updates to outdated or legacy systems.** Because technology is constantly changing, a sound strategy is to first assess the existing system capabilities by evaluating the capacity of the current systems to support adaptation and integration with the evolving technologies. Once this evaluation is complete, an agency can develop requirements for the new system, determine whether any components can be maintained, and identify data archiving capabilities and needs. Focusing on the evolution of capabilities for specific subsystems to allow for incremental changes and updates (i.e., one large replacement of TMS is not always the answer) is important. Establishing ongoing maintenance and support for the existing system while transitioning to a new system is a critical step, as is coordinating with both internal agency departments and external agencies to determine overlaps in data and technologies that can be streamlined and shared. Finally, assessing personnel roles to determine skill sets and identify any adjustments need to be made to match the vision of the new system and its operations is helpful.
- **Integration issues with new and existing systems.** To avoid this challenge, engaging system integrators and vendors early in the planning process to discuss interoperability and to figure out options to issues that may be unique to each system is important.
- **Lack of ability to collect and manage large amounts of data.** As more data sources become available, planning for data collection and data management is important. Processes need to account for considerations for data acquisition, governance, storage, and analysis:

- For acquisition, the capacity of the existing system to collect large amounts of data is assessed for both the near term and long term, along with procurement options. Latency in data collection is considered as it varies based on the agency's needs.
- For governance, exploring opportunities where data collection can serve multiple purposes is important. This step also is where privacy, security, and management concerns can be addressed.
- For storage, agencies need to consider the barriers to using private or public cloud services. The variety and type of data to be stored, the duration of time the data are anticipated to be stored, and the granularity of the data affect the storage requirements.
- For data analysis and processing, an assessment on the system's current data analysis and management capabilities is performed. Analysis tools and staff skillsets required are reviewed.

In addition to the previously discussed challenges and strategies, several knowledge gaps (presented in the next bulleted list) are becoming more prevalent as TMS developments move forward. These gaps exist in relation to data management, control algorithms, and data science. The future success of TMS depends on agencies closing these gaps. Handling an influx of data from a variety of sources, integrating data availability, and compensating for gaps in data science are the most prevalent barriers to overcome:

- How to handle incoming data from a variety of data sources?
 - The influx of data from third-party data providers, a mix of reported data and crowdsourced data and soon, data transmitted from connected vehicles needs to be managed.
 - Existing systems are not equipped to handle the full range of data that they may have access to in the future. Having the most up-to-date data analytics platforms can help prepare for this situation.
- How to integrate data availability from traditional and emerging sources, such as probe data, with traditional system control algorithms?
 - Most of the control algorithms are based on traffic flow theory data types, which require data metrics on different points of roadway. The data are collected from traditional sources and include point measures such as speed, density, and volume obtained from roadway sensors. However, the most cost effective data source is probe data, which provides data on individual trips rather than data at specific locations. Algorithms may need to be developed that rely more on probe or trip-based data than on point data.
 - Agencies interested in adapting control algorithms for traffic signals and ramp metering currently lack an established protocol for incorporating probe data, once they are validated for accuracy and completeness, to improve operations.

- How can transportation agencies fill their data science gap?
 - Traditional transportation engineering programs do not train engineers in data management and governance, but the demand in transportation for data scientists who can perform data analysis is increasing.
 - Employee acquisition and retention may be difficult unless agencies are in a jurisdiction that recognizes better pay and has a defined career path for these data scientists.

CHAPTER 3. WHAT IS A CONOPS?

This chapter explains what a ConOps is by providing the general purpose of a ConOps and then further detailing the structure. The “purpose” section discusses the main questions the ConOps sets out to answer. The “structure” section discusses the seven main elements of a ConOps and the information to be included in each element. Where appropriate, examples from agency efforts to develop a ConOps for the NextGen of their TMSs are provided. After describing the core elements of a ConOps in this chapter, chapter 4 sets up its relationship to agency planning activities, followed by a discussion of the high-level role of a ConOps in the project development process (chapter 5).

PURPOSE

The ConOps is probably the most important artifact of the systems engineering process because the system requirements, test plans, acceptance procedures, etc., flow directly from the concepts and use cases described in the ConOps. Subsequently, system requirements are developed directly based on contents of the ConOps document. These requirements are discussed later in chapter 7.

The ConOps is a living document, and it can be updated, revised, and amended throughout its lifecycle to reflect the changing needs of the NextGen TMS. The ConOps is available, and relevant to all stakeholders in the system, despite their background or role within the system. In the context of a TMS, the ConOps is readable on all hierarchical scales, from high-level decisionmakers to the TMS users and operators. At its core, the ConOps attempts to answer the who, what, when, where, why, and how for the system in general terms. Each of these are described using general examples and discuss how they influence the ConOps. The following examples are questions the ConOps will answer:⁽³⁾

- **Who** are the stakeholders involved with the system?
- **What** are the elements and the high-level capabilities of the system?
- **Where** is the system located and what is its geographic extent?
- **When**—What is the sequence of activities that will be performed?
- **Why**—What is the problem or opportunity addressed by the system?
- **How** will the system be developed, operated, and maintained?

STRUCTURE

FHWA recommends use of two standards to prepare a ConOps: the American National Standards Institute (ANSI) ConOps standard (ANSI/AIAA G-043-1992) and the IEEE ConOps Standard (P1362 V3.2).^(29,30) Although organized differently, both contain similar contents. For this section’s discussion, the ANSI standard for the preparation of operational concept documents is used.⁽³¹⁾ The standard provides a basis for developing a standard ConOps document for any complex system, recommending that a ConOps document “...describe system characteristics from an operational perspective,” and it answers the question for each stakeholder, “What does it [the system] look like from my point of view?”⁽³⁾ The following seven main elements of the ConOps are discussed in detail in individual sections after the list:

- Scope.
- Reference Documents.
- User-Oriented Operational Description.
- User Needs.
- System Overview.
- Operational and Support Environment.
- Operational Scenarios.

Scope

The scope presents an overview of the entire ConOps. This section provides a broad overview of the entire ConOps broken down further into the following elements:

- **Outline of the Document**—The outline of the document provides a descriptive layout catered to the TMS. The layout frames all components of the system being developed.
- **Purpose of the System**—The purpose of the system is explicitly described. The purpose can be expressed through identifying the need for the TMS by highlighting current system performance, needs, and areas for improvement. Given the integration of operations into the larger transportation planning processes, for example, the TSMO strategic plan, addresses this relationship.
- **Main Goals**—The main objectives of the system are highlighted in this section. At this point in the document, providing indepth descriptions of the NextGen system objectives from an operational standpoint is not necessary. (Higher level systems operations are discussed in the User-Oriented Operational Description Section of this chapter.)
- **Identify the Intended Audience**—Identifying the intended audience is a crucial element of the ConOps because it drives the voice of the document. The intended audience consists of those stakeholders who are within the system scope or are affected by the system in some form. By identifying the audience in the scope, authors of the ConOps are better equipped to communicate the range of topics.
- **Set Boundaries on the Scope of the System**—The boundaries set define the groups who are included in the NextGen system. Additionally, the boundaries identify any entities that may require external interfaces to the NextGen system.
- **Describe an Overarching Vision for the System**—The overarching vision is a statement that best describes the future workings of the system. The vision explains what the NextGen system looks like when all the stakeholders’ needs are met in every capacity. Additionally, it describes how the system works, given that each stakeholder has a developed understanding of the system’s purpose.

The scope shown by the plan set forth in the Virginia DOT’s (VDOT) *Statewide Advanced Traffic Management System (ATMS) Operating Platform: Concept of Operations* is a prime example of how a TMS incorporates the scope for a ConOps.⁽³²⁾ The ConOps describes VDOT’s vision to increase its TOC interoperability and leverage technology to achieve more efficient

operations and to improve mobility, safety, and the environment in the Commonwealth of Virginia. Their scope clearly identifies the purpose and main goals of their system and provides a document overview that identifies the VDOT's intended audience. The VDOT includes the following statement that clearly identifies the audience:

This [audience] includes VDOT upper management, VDOT Central Office staff, VDOT Regional Operations Directors, VDOT TOC Managers, TOC Operators, Operations Planners, system engineers, designers, and integrators. Users are expected to read the ConOps document to determine whether their representative has correctly specified their needs and desires and that they have been correctly captured in this document.⁽³²⁾

As the statement shows, the ConOps document is written for a broad audience. The VDOT scope also contains a document overview that lists each of the six sections of their ConOps document that is descriptive and transparent. The scope sets the tone for the rest of the document because it provides the overview for the NextGen TMS integration project spanning multiple jurisdictions and agencies.

Reference Documents

In the reference documents section, all the resources used to develop the ConOps are listed. The list organizes the gathered information, but it also can show readers where to seek additional clarifying information and guidance. Note that the referenced documents are distinguishable from a bibliography. Although similar, the documents included in the list specifically reflect the goals of the system. According to FHWA's *Developing and Using a Concept of Operations in Transportation Management Systems* manual, the following types of reference sources and their descriptions are typically listed:⁽³⁾

- **Business Planning Documents**—Documentation and resources associated with business processes for an agency and region.
- **Concept of Operations**—Other systems' ConOps that complement the design of the system in question.
- **System Expertise**—Documentation of human resources—individuals who singularly add unique and valuable experience to the development of the system in question.
- **Requirements**—The requirements of other systems, which provide detailed insight into their workings.
- **Studies to Identify Operational Needs**—Reviewed documentation related to the system in question, or another anticipated, similar, system that addresses operational needs.
- **System Development Meeting Minutes**—Documentation of most meetings associated with the development of the system in question.

VDOT provides a good example of the use of reference documents. VDOT used the following reference documents during the creation of its *Statewide ATMS Operating Platform: Concept of Operations* document:⁽³²⁾

- “IEEE Guide for Information Technology - System Definition - Concept of Operations (ConOps) Document” in *IEEE Std 1362-1998*.⁽³⁰⁾
- I-66 ATM system ConOps.⁽³³⁾
- WSDOT ATM ConOps.⁽³⁴⁾
- VDOT Northern Virginia Go-Forward Plan.
- OpenTMS Enterprise System—System Requirements Specification.
- OpenTMS operator training manuals.
- Virginia Traffic (VaTraffic) System Requirements Specification.
- Lane Closure Advisory Management System Concept of Operations.
- Software Development and Integration for the Hampton Roads Smart Traffic Center Request for Proposals (RFP).
- *DYNAC System Design Document*.⁽³²⁾
- *Virginia’s Long-Range Multimodal Transportation Plan: VTrans2035 Report to the Governor and General Assembly*.⁽³⁵⁾
- VDOT/Open Roads Transportation Operations Technology Support Services Contract (2009).
- VDOT/Transdyn Transportation Operations Technology Support Services Contract (2009).

VDOT used other DOT ConOps documents, traffic system requirements, business planning documents, and more. The comprehensive list provides a databank from multiple sources for readers to reference, thus making it a prime example of a proper reference document section.

User-Oriented Operational Description

The user-oriented operational description addresses how organization or system-specific goals and objectives are accomplished. The operational description is addressed through discussions of who the users are and what the users do, the order of user operations, the stepwise processes of user activities, organizational and personnel structures, and how the users interact. Careful discussion that relates the similarities of this element with the operational scenarios provided occurs later in the ConOps.

The user-oriented operational description describes the intentions of the system from the user’s point of view. Knowing who the users are and what the users do within the system, also known as the user activities, is the first step. In the NextGen system, multiple users, whose activities are explained with event-specific information, have varying roles. The event-specific information, or order of user operations, demonstrates the incremental process of user activities. These incremental steps, referred to as the operational process procedures, are best represented by visual diagrams that present the relationships with respect to time and event context. Organizational personnel structures are also defined in this section. The definitions of the system personnel are system specific and include the hierarchal relationships between users. Displaying this information visually in graphics, charts, and tables, which provides readers with a clear understanding of personnel interactions, is also helpful.

Note the apparent similarities between user-oriented operational descriptions and operational scenarios, both of which focus on the user. The user-oriented description focuses mainly on the roles of the users, however, and the scenarios create hypothetical circumstances for users to follow. Operational scenarios are formed based on the user-oriented descriptions.

An example of a NextGen TMS that employs sound user-oriented operational descriptions is GDOT’s Regional Traffic Operations Program (RTOP) ConOps.⁽³⁶⁾ The third section of GDOT’s ConOps document contains two tables: “Agency Responsibilities” and “Team Roles” that provide descriptive outlines. The roles outlined in the first table (table 2) organize the roles between the GDOT and the local entity. The tasks are then further broken down in the second table. Table 3 provides the role, procedures, and processes to be followed by the RTOP, program manager, corridor manager, GDOT lead, and local lead for system evaluation and baseline.

Table 2. “Agency Responsibilities” from GDOT RTOP ConOps.⁽³⁶⁾

| Program Component | GDOT Lead | | Local Lead | |
|--|-----------|-------|------------|-------|
| | GDOT | Local | GDOT | Local |
| Corridor signal timing | Yes | — | Yes | — |
| Timing adjustments | Yes | — | — | Yes* |
| Maintenance | Yes | — | — | Yes |
| After-hours and emergency response | — | Yes | — | Yes |
| Detector, communication, and surveillance repair | Yes | — | Yes | — |
| Peak-hour management and monitoring | Yes | — | — | Yes |
| Major repairs | — | Yes | — | Yes |

—No data.

*Subject to GDOT approval.

Table 3. “Team Roles” from GDOT RTOP ConOps (System Evaluation and Baseline portion of GDOT table).⁽³⁶⁾

| Task | RTOP Manager | Program Manager | Corridor Manager | Local Agency | |
|---|--|--|---|---|--------------------|
| | | | | GDOT Lead | Local Lead |
| Kickoff meeting with local agency | <ul style="list-style-type: none"> • Make initial contact with local agency. • Attend kickoff meeting. | Attend kickoff meeting. | <ul style="list-style-type: none"> • Conduct kickoff meeting with agency. • Establish management and communications protocols. | <ul style="list-style-type: none"> • Provide initial feedback on corridor condition. • Communicate program approach to local agency staff. • Provide supporting documentation for inventory. | Same as GDOT lead. |
| Initial system maintenance and operational evaluation | Review reports furnished by program manager. | <ul style="list-style-type: none"> • Collect, review and archive inventory. • Provide summary data for RTOP manager. | <ul style="list-style-type: none"> • Conduct field inventory: <ul style="list-style-type: none"> ○ Controller and cabinet hardware/software. ○ Historical counts. ○ Intersection design. ○ Obtain or establish signal permit. ○ Planned projects and construction. ○ Planned special events. • Prepare inventory data and submit to program manager. | Support data collection as needed. | Same as GDOT lead. |

| Task | RTOP Manager | Program Manager | Corridor Manager | Local Agency | |
|---|---|--|---|--|--|
| | | | | GDOT Lead | Local Lead |
| Baseline operations | — | Document changes to initial signal timing. | Using information from initial system evaluation, update existing signal timing plans. | Provide input on initial signal timing plan updates. | Implement signal timing updates based on corridor manager's recommendations and approve corridor manager to implement. |
| Maintenance recommendations | Approve and make comments on suggested recommendations made by program manager. | Compile and prioritize recommendations made by corridor managers. | <ul style="list-style-type: none"> • Develop recommendations for maintenance repairs for corridors. • Review recommendations with local agencies. | Advise corridor manager of known maintenance issues and recurring problems. | <ul style="list-style-type: none"> • Work with corridor manager to identify maintenance issues and to develop corrective action plan. • Provide a plan and schedule for addressing maintenance requirements. |
| System surveillance, monitoring and operational improvement recommendations | Review and approve recommendations. | Summarize recommendations and submit to RTOP manager for approval. | Develop recommendation for system enhancements that could improve operational performance. | <ul style="list-style-type: none"> • Provide input into needed recommendations. • Review final recommendations and consult with RTOP manager on implementation strategy. | Same as GDOT lead. |

—No data.

User Needs

The user needs section discusses how agency- and region-specific goals and objectives drive system requirements, and how the needs answer the question of “what” is required by the agencies or region that the TMS support. User needs are defined as identifiable capabilities that ultimately lead to solving specific problems or achieving certain goals by the desired system; capabilities are not limited to what already exists in the current system. As noted in the first sentence, the user needs work to answer the “what” without going into so much detail as to determine the “how.” User needs are problem based and do not imply or indicate a solution but instead give designers flexibility in eventually solving the problem. User needs are typically gathered through direct stakeholder engagement workshops and other coordination efforts. The coordination efforts revolve around the objective of the stakeholders providing input for what they require out of the new system.

The 2011 Core System ConOps was prepared by the Research and Innovative Technology Administration for USDOT’s NextGen of integrated transportation systems.⁽³⁷⁾ Their approach to gathering user needs is a sound example for demonstrating the interdisciplinary avenues agencies can take to gather input from stakeholders. As outlined in their ConOps, through large workshops; one-on-one meetings; and other venues with stakeholders from multiple agencies, universities, organizations, and companies, important discussions were achieved. Participants were able to focus on fleet operations, transportation operations, and back-office systems in various workshops hosted in major cities. On a smaller scale, one-on-one meetings and document exchanges proved just as useful in coordinating efforts and provided the agency with additional input on these topics. At the conclusion of the agencies’ outreach events, they consolidated and summarized the input they gained from the various methods of communicating with stakeholders by specific problems, needs, and rationale.

One example of an identified problem, need, and rationale gathered from a workshop is as follows:

Problem: “There currently is no way to monitor and transmit transit parking information.”

Need: “Provide a means to determine transit vehicle parking availability.”

Rationale: “Monitor transit capacity.”

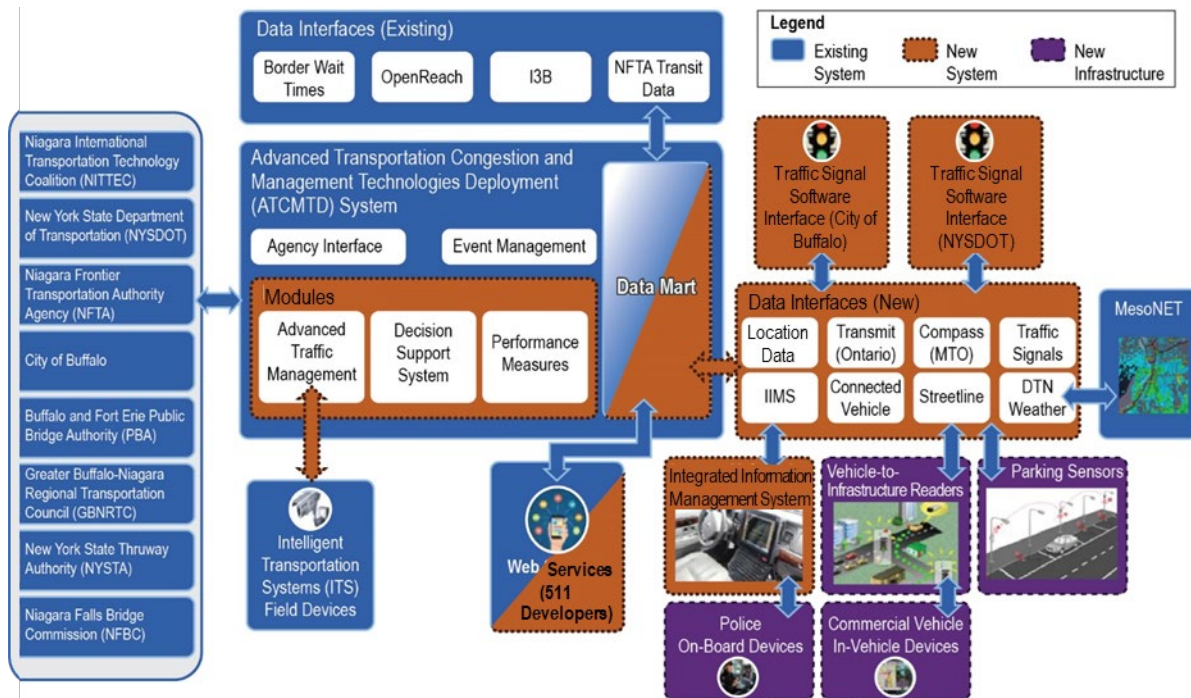
As this example shows, the stakeholder was able to identify a problem within the existing transportation operations with the intent of improving transit parking capacity. This example was pulled from an extensive comprehensive table that uniquely identified each problem by number. This practice of organizing user needs ultimately leads to organized consensus gathering and drives the focus of the system.

System Overview

This section of the ConOps summarizes information found throughout the ConOps. The system overview discusses the interrelationships of key subsystems and components. It focuses on the scope—geographic boundaries of the system and the breadth of the stakeholders—and the interfaces, both internally and externally to the TMS.

Similar to the scope, this section of the ConOps provides a general outline of the system. Since the NextGen TMS relies on multiple interdisciplinary entities, this section provides a high-level description of each subsystem and component. Although most of the information in the system overview is reiterated throughout the course of the document, the purpose of including this section is to clearly define those relationships. To help readers better visualize all the interrelationships, including a network diagram covering the communication paths is good practice. The network of users defines the breadth of the stakeholder involvement and how the multiple interfaces relate both internally and externally.

The use of a system overview is exemplified through the efforts of the NITTEC in the Buffalo, NY (United States)—Ontario (Canada) region. NITTEC is a coalition of transportation planning and operations agencies in the United States and Canada working together to improve mobility and enhance international border crossing in the region.⁽³⁸⁾ Like other transportation coalitions in the United States, the individual agencies handle their typical recurring traffic and congestion and manage their facilities as expected, without much operations coordination with others. Once a major unexpected event occurs, even with the existence of NITTEC, the region was not fully ready to address the situation in the most efficient manner, use available alternative routes, coordinate operations, and work as a team to manage the event as efficiently as possible. Through an ATCMTD grant, NITTEC is working to coordinate its operations through a single management system (figure 12).



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DTN = Data Transmission Network; IIMS = Integrated Incident Management System; MTO = Ministry of Transportation Ontario.

Figure 12. Diagram. Overview of a proposed Niagara International Transportation Technology Coalition (NITTEC) Advanced Transportation Congestion and Management Technologies Deployment (ATCMTD) system concept.

Their ConOps document seeks to answer the following questions:¹

- How can NITTEC move commercial vehicles across the border quickly and safely?
- How can the coalition move passenger cars across the border safely and efficiently?
- What systems can NITTEC use to share real-time border crossing data with passenger vehicles to allow them to plan their trips better and avoid crossing at peak times if they can alter their travel time?
- How can NITTEC disseminate traveler information to both commercial vehicles and passenger vehicles in realtime?
- How can the coalition reduce border crossing delays?

¹WSP USA, Consensus Systems Technologies, and Highland Planning. 2020. *Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Project – Planning Phase – Phase 1 Concept of Operations*. Buffalo, NY: Niagara International Transportation Technology Coalition. (Unpublished.)

- How can NITTEC improve the dissemination of predictive border wait times to truckers? (Trucks must declare which border they intend to pass through before arrival. The timeline is 1 h for regular shipments and 30 min for Free and Secure Trade shipments).
- What capabilities does the region have to reroute cars and commercial vehicles due to congestion, construction, incidents, special events, weather, etc.?
- How can NITTEC improve parking management within the City of Buffalo?
- How can the coalition receive more information from the trucking associations and other potential sources about the number of trucks approaching each border crossing?
- How can the coalition improve or enhance communication within the region?
- How can the coalition improve incident response or clearing time?
- What partnerships need to be made to disseminate parking/weather data in realtime?
- How can NITTEC disseminate weather and operational conditions specifically to trucks in realtime (e.g., cases of interstate closures that have been specific to commercial vehicles in New York, New Jersey, and Pennsylvania due to weather)?
- Can agencies within the region share camera video?
- What can NITTEC do to avoid delays at the border in terms of personnel-related issues?

NITTEC ATCMTD System Overview Initiatives¹

1. Improve Border Crossing Performance and Travel Time.

- 1.1 Define operational performance goals for border crossing travel time and delay.
- 1.2 Dynamically monitor border crossing operational status.
- 1.3 Develop and implement strategies to balance border performance and travel time within the set thresholds.

2. Improve Commercial Vehicle Operations and Safety.

- 2.1 Provide in-vehicle real-time traffic, parking, and weather information to commercial vehicles to facilitate trucks operations from the Pennsylvania border and the area of Rochester, NY, into Buffalo and the border crossings.
- 2.2 Provide truck parking management support to accommodate trucking and trucker needs.

3. Expand Regional Smart Mobility.

- 3.1 Expand ICM to major highways in the region as well as the City of Buffalo main corridors and routes.
- 3.2 Expand the I-190 ICM corridor from the east, to Rochester and from the south, to the Pennsylvania border.
- 3.3 Upgrade municipal signal systems on potential alternate routes.
- 3.4 Deploy a parking management system downtown and around major trip generators, such as hospitals, stadiums, special events, downtown business areas, and more.
- 3.5 Integrate real-time and forecast weather information system and the alerting applications within the region.
- 3.6 Upgrade the regional ATMS to have a fully integrated regional smart mobility system.
- 3.7 Develop a dynamic regional decision support system and performance measures application to ensure optimized operational level of service.

4. Improve Incident Management.

- 4.1 Improve coordination among responders by integrating with additional 911 computer-aided dispatch systems and expanding the regional information exchange network initial project to ensure a robust and timely information exchange, including incident location, response, and incident status.
- 4.2 Integrate with onscene emergency management service providers using the Integrated Incident Management System concept employed as a pilot project in New York City, NY.

5. Provide for Operational Integration Within Niagara Frontier Transportation Authority (NFTA) and With Regional Smart Mobility.

- 5.1 Integrate various NFTA real-time data sources to improve operational efficiency.
- 5.2 Integrate NFTA operational data and systems within the regional mobility concept.
- 5.3 Improve NFTA transit incident management by integrating various steps and process within the agency and with various involved departments.
- 5.4 Offer transit as an alternative strategy to highways and vice versa.
- 5.5 Provide real-time transit information to public via 511NY and other dissemination tools.

¹WSP USA, Consensus Systems Technologies, and Highland Planning. 2020. *Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Project – Planning Phase – Phase 1 Concept of Operations*. Buffalo, NY: Niagara International Transportation Technology Coalition. (Unpublished.)

NITTEC ATCMTD System Overview Initiatives¹

6. Using Real-time and Forecasted Weather Information for ATM Strategies.

- 6.1 Implement a robust real-time and weather forecast and alert system to warn truckers and motorists of inclement weather and delays.
- 6.2 Integrate with New York State DOT and New York State Thruway Authority RWIS units currently in place or being expanded via the Mesonet project.

7. Provide Travelers With Enhanced Real-Time Information.

- 7.1 Provide real-time and forecasted multimodal, multiagency transportation network information via 511NY and other applications.

8. Enhance Data Collection, Fusion, Distribution and Archiving.

- 8.1 Enhance the ability to collect, fuse, distribute and archive available data for all manner of performance measures, performance management, real-time operations, and real-time information.

Operational and Support Environment

In NextGen TMSs, the environment is the world in which system operations take place. Information about the system's environment in terms of its facilities, equipment, hardware, software, operational procedures, personnel, and support creates this world, which takes on both operational and physical meanings. The operational realm covers operational procedures and personnel, i.e., the existing stakeholders operating the current system and potentially new stakeholders. The physical realm implies the actual software, hardware, and equipment necessary for performance. The operational and physical support comprise the world in which the NextGen system operates and often overlaps.

The operational environment consists of the following elements:

- **Personnel.** This environment includes personnel required to staff and operate the physical facilities. Similar to the users outlined in the user-oriented operational descriptions, the personnel cover all staffing necessary to the NextGen system.
- **Operating Support.** In addition to traffic engineers, local government agency personnel, and stakeholders, the operating support environment also includes employees who are not as obvious to the functionality of the operation. Those support personnel include the business side of the industry, for instance, human resource workers, accountants, and financial analysts.
- **Operational Procedures.** The operational procedures provide answers to the questions “what” and “when.” Specifically, these procedures reveal what the users and system components are doing and under which conditions.

¹WSP USA, Consensus Systems Technologies, and Highland Planning. 2020. *Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Project – Planning Phase – Phase 1 Concept of Operations*. Buffalo, NY: Niagara International Transportation Technology Coalition. (Unpublished.)

The physical environment consists of the following parameters:

- **Facilities.** The facilities discussed include the buildings, hubs, and any operation centers involved in the system.
- **Equipment and Hardware.** NextGen TMSs may have more advanced equipment because more instruments are required for reporting the exponentially higher amounts of data sources. A higher level description of each piece of equipment and hardware is discussed so readers are aware of the instrumentation required and their functionality within the system.
- **Software.** Another higher level description of the newly implemented software used by the NextGen system is explained in the ConOps. With a new system, new software has been likely implemented.

The information in this section is likely covered in various other sections of the ConOps document. For instance, the operational procedures already may have been outlined in the user-oriented operational description. Therefore, the operational and supporting environment aims to define the relationship between the physical and operational realms of the system and tie the “world” together.

VDOT’s Statewide ATMS Operating Platform ConOps document (sections 3.4: Modes of Operation, 3.5: User Classes and 3.6: Support Environment) exemplifies the use of operational and support environments.⁽³²⁾ The modes of operation section details the physical software and hardware used throughout the operations (i.e., equipment, software, hardware). The user classes section identifies the operational personnel, ranging from administrators who control and configure the system to guests who are limited to “read-only access.” The last section provides insight into the outside production, maintenance, after-hours, and onsite system administration support (operating support). As this VDOT’s statewide ATMS shows, readers gain a benefit from understanding the logical relationship between the physical and operational support teams.

Operational Scenarios

The operational scenarios are the culminating descriptions of how a particular and specific scenario would be handled. This subsection defines an operational scenario and discusses how the scenario is used to demonstrate the who, what, when, where, why, and how in terms of an example incident. This section discusses the basic elements of the scenario, including each user of the system, a variety of user classes, stress and failure scenarios, and multiple circumstance scenarios with subevents. These scenarios are presented to illustrate the broadest extent and capabilities of the TMS.

An operational scenario is a potential situation told like a story from the perspective of one of the users of the system. The author of the ConOps creates and walks through a possible user experience of the system and defines how the system would affect the user under the designed circumstances. The situations created and described range from typical day-to-day activities to high stakes and stressful conditions. The stressful conditions, or “failure conditions” are situations that could hypothetically push the system toward failure. The operational scenarios

told from the broad audience range represent every potential user of the NextGen system. Furthermore, the scenarios involve multiple events to properly create the story and ensure an explanation of the full extent of the system capabilities is provided.

An example of effective operational scenarios used in a NextGen TMS is the RTOP ConOps prepared by GDOT.⁽³⁶⁾ The ConOps includes three descriptive operational scenarios. The first is a construction or incident scenario that describes how the system would deal with a water main break disrupting traffic along a main route. The second is a detour scenario that causes partial closure on a freeway and a detour of traffic. The last scenario describes inclement weather in which a dense fog in a low area causes video detection failure. Each scenario, which ranges from typical to extreme, enables ConOps readers to see the new system in action.

Another good example of operational scenarios is in the FHWA's *Weather-Responsive Traffic Management Concept of Operations*.⁽³⁹⁾ This document deals directly with responding to weather-related issues and solutions and has an entire section dedicated to "Weather Scenarios." Each scenario example includes a description of the weather event; the impacts of the weather event; a table chronicling the time sequence of the events; advisory, control, and treatment strategies; and a measurement of the system's effectiveness. By including the characteristics of the weather event and an analysis of the impact the scenario has on the health of the roadway and users, the weather examples showcase the system capabilities. Due to the specific nature of the system in this FHWA document, all conceptual scenarios are weather related. While an extreme weather event is a substantial example for a NextGen ConOps to include because it can really test the limits of the system, the NextGen TMS operational scenarios included provide broader hypothetical situations as well.

CHAPTER 4. CONOPs AND TMS PLANNING

Chapter 3 introduced the importance of the ConOps and each of its elements. Chapter 4 now connects the ConOps to planning activities focused on improving or replacing a TMS. This chapter discusses how the ConOps can be used in the planning and preparation of the agency's TSMO program's multiyear plan, a multiyear plan for the TMS, or TMS feasibility studies. It describes how the ConOps both feeds, and is fed by, the larger overall transportation planning process. A range of possible projects, processes, and steps associated with planning, developing, and implementing TMSs are included, as well as issues to consider and practices with planning for and developing specific improvements (e.g., software platform, data subsystems, telecommunication media). Challenges, lessons learned, and other issues encountered by agencies that already have taken steps to replace or enhance their systems or specific improvements also are covered.

OVERVIEW

Many agencies do not conduct feasibility studies for a TMS, and many may not have multiyear transportation management strategic plans to lay the groundwork for building TMS plans. However, developing and integrating plans for a TMS into existing agency planning efforts is critical, especially for TSMO plans and ITS strategic plans. Leveraging existing planning efforts and plans is crucial when planning for TMSs and assessing the aspects of a TMS that may need improvement to meet the needs of an agency, region, or any specific geographical area. Stakeholders typically start from scratch when they begin exploring options to pursue or plan for improving TMSs, as nationally developed resources are still being developed to assist with these studies. This chapter discusses a series of feasibility techniques and methodologies conducted in support of planning for the NextGen TMS.

The success of a TMS begins long before a deployment project advances, software is written, or equipment is deployed. The TMS serves a specific need of the agency, other agencies in the region or State, stakeholders, or service providers. While development and deployment of the TMS is based on and traced back to agency priorities and needs in these planning efforts, user needs and the ConOps, purpose, and scope of the TMS project are developed well in advance of initiating a project to improve or replace a TMS.

AGENCY AND PROGRAM PLANNING

Agencies at all levels (State, county, municipality) plan for the improvement and maintenance of their multimodal transportation networks. The plans cover a broad swath of modes and address needs as far out as 20–25 yr. These high-level planning steps, or those plans developed for a wider reaching agencywide or statewide perspective, provide input from program rather than project leaders. This process discusses various plans, such as the agency's strategic plan and long-range transportation plan as well as the more directed short-term plans, like the (statewide) TIP. Similarly, more focused plans, like TSMO program plans and ITS strategic plans, provide guidance for the ConOps through agencywide goals and objectives and through information on how the ConOps can both gain from and support the program. This section focuses on the

different planning activities agencies typically go through. In the following section, the relationship between these planning activities and the ConOps is discussed.

Current agency practices and plans (e.g., strategic plans, regional operations plans, ConOps) are used as a preliminary framework to assess TMS needs and performance and contribute to planning a TMS. This section addresses the importance of integrating TMS planning efforts with agency or regional plans, conducting feasibility studies (especially with new TMSs or adding new operational strategies to a TMS), and developing a plan for a TMS. Issues to consider during the process, such as examples of current practices, also are included.

Connecting Planning for a TMS to Agency or Regional Plans

Before a TMS can be developed and implemented, an agency completes a planning process. Planning for developing, installing, and operating a TMS is most effective when driven by objectives and desired outcomes. The rationale is to link planning processes and traffic operations so that the performance of the network is enhanced in an efficient manner to meet agency, regional, or State goals. When planning for a TMS, agencies and stakeholders should consider appropriate performance measures that can show the progress toward reaching these goals. Selected performance measures reflect the data that can be collected by the system or acquired from other systems or parties.

Planning Considerations

TSMO activities are at the core of transportation agencies' missions to provide safe and efficient transportation. TMSs enable many of the TSMO activities that support agencies' missions. Planning helps agencies identify how the TMS operates and is structured, including any services provided to external entities. Agencies can then integrate the requirements needed for a TMS into their capital program, TSMO program, or regional transportation plan (RTP) at the level of detail applicable to that plan or program. Documenting the TMS requirements in a plan formalizes the planning process and can help guide future system enhancements.

Scenario planning is often integrated into the long-range transportation planning process. Long-range scenario planning involves strategic, high-level questions about major changes in the external operating environment, such as changes in the economy, demographics, technology, and the environment. The goal of scenario planning is to ensure that regardless of what system is built, the system is adaptable to potential future changes, and the agency can use these scenarios to get a clearer idea of the implications of major changes.

Short-term scenario planning is much more operational in nature and centers around how the TMS is operated and managed under different conditions, such as planned events (e.g., sporting events, construction work zones); incidents (e.g., closed lanes or inclement weather); and typical day-to-day operations. The use of modeling and simulation tools can facilitate the assessment of the TMS in various scenarios and help agencies determine the best range or combination of scenarios to include and use as the basis around which the planning evolves. The integration of scenario planning into long-range planning processes is especially important for prioritizing the needs for future investments of operations in transportation. A six-step scenario planning process

can follow the same process defined in the *FHWA 2011 Scenario Planning Guidebook* as modified for TMSs and operational strategies:⁽⁴⁰⁾

1. **How should we get started?** Scope the effort and engage partners.
2. **Where are we now?** Establish a baseline analysis. Identify factors and trends that affect the State, region, community, or study area.
3. **Who are we and where do we want to go?** Establish future goals and aspirations based on values of the State, region, community, or study area.
4. **What could the future look like?** Create a baseline and alternative scenarios.
5. **What impacts will scenarios have?** Assess scenario impacts, influences, and effects.
6. **How will we reach our desired future?** Craft the comprehensive vision. Identify strategic actions and performance measures.

Results of agencies' planning work also can be captured in a multiyear TMS plan that identifies resources, future projects, and procurement methods. The TMS plan, or elements of the plan, can be included in agency transportation or TSMO plans, capital programs, and budgets, eventually trickling down to project level where these elements feed the ConOps. Key elements of the plan include identifying linkages to the agency's TSMO plans and long-range scenario plans, MPO long-range plans, and other agency plans. The document is used as decisions are made in support of the design and development of the TMS and integration of projects and allocation of funds in future budgets to provide the resources needed for the agency to implement the plan. The multiyear plan identifies any enhancements or improvements that may be needed over a 5–10-yr period, ongoing operations and maintenance requirements, and administration needed to support the TMS over the planning horizon of the study.

An RTP, which is normally produced by an MPO, can also serve as a blueprint for transportation system investments within the region across all modes and be included as input to the ConOps. The RTP ensures that transportation projects are completed collaboratively across various agencies and jurisdictions. The RTP examines the regional transportation system by looking 20 yr or more into the future and includes both short-range and long-range strategies that lead to the development of an integrated multimodal system.

Planning in subareas and corridors entails accounting for the impacts of using a range of operational strategies and TMS with the required functional capabilities at varying geographical scales. A subarea is a smaller portion of the region. Planning for a smaller scale geographical area requires an agency to plan in greater detail, including analysis and system feasibility assessment. Examples of subareas include a downtown area, a municipality, an activity center, or another type of area within a region. A corridor is typically a group of routes that run parallel, either through a region or are contained within a region. Compared to a subarea, a corridor is a larger scale travel space.

When agencies are considering implementing a TMS at a regional level, understanding what range of operational strategies may be used and where they may be implemented is important.

Agencies can then determine the capabilities needed by a TMS to assess how it may affect mobility at the subregional levels. Through this determination, the planning process better reveals specific elements in these systems that support mobility goals.

The use of accurate and reliable data during the planning phases is essential because these data enhance an agency's ability for estimating the potential benefits to the transportation network from implementing a TMS, actively managing and operating traffic, using new operational strategies, or expanding the services currently provided. Therefore, obtaining sound data helps agencies determine which type of TMS operational strategies and functions are most beneficial.

Programming and Budgeting

At the programming level, securing funding is a competitive process due to limited resources and high demand for other projects. Programming and funding processes can vary from State to State. Generally, a TMS can be included in TIPs, long-range plans, and short-range plans if it can support the plan's goals and objectives. However, TMS implementation projects may have to compete with other projects to be approved for funding. TSMO managers must understand their agencies' budgeting and project programming processes to successfully fund TMS projects.

At this point in the process, proposed TMS enhancements (e.g., added functionality), expansions (e.g., area of coverage), new capabilities, or entire replacements of TMSs are integrated into the multiyear budget plans. All the needs and supporting projects in a TMS study help to bolster the prioritization, justification, definition, and scope necessary to support a project being integrated into an agency's multiyear plan and budgets for all capital or operational expenditures (e.g., MPO TIP).

A key element of the programming process is project prioritization. Traditional prioritization processes may not have the ability to accurately assess the benefits that are often accrued by a TMS. In this case, TSMO managers advocating for updates to the prioritization process to account for these benefits is important. Some of the most important benefits that TMSs provide are to travel time reliability.

Assessment techniques that estimate benefits based on average roadway conditions and average traffic flows do not consider fluctuations that can dramatically affect travel time reliability. Analytical techniques that incorporate measured benefits or those approaches that accurately model stochastic fluctuations in travel conditions are examples of methods that can more accurately assess TMS benefits. Active participation in the programming process is an effective way to ensure that benefit assessments used for project prioritization accurately reflect the benefits that a TMS can deliver.

Effective Practice: Prioritize Operations at the Programmatic Level

Many of the challenges with implementing TMSs and improving operational strategies can be addressed at the programmatic level. Caltrans is working to improve its operational strategies by advancing its TSMO program. In 2013, Caltrans used an FHWA regional operations forum (ROF) and a CMM assessment to identify organization gaps and a tailored approach for statewide implementation.⁽⁴¹⁾ Additionally, TSMO was integrated into the 2015–2020 Caltrans Strategic Management Plan as a major component tied to the State's goals.⁽⁴²⁾ Caltrans placed a

strong emphasis on improving operations and performed the following additional actions to advance TSMO and ICM in California:

- Identified the top strategic corridors in California.
- Conducted a connected corridors pilot in Los Angeles, CA.
- Created a statewide connected corridors program.
- Created a 3-d ROF and CMM self-assessments that focused on corridor operations that included local partnering agencies. This effort resulted in corridor-level implementation plans that lead to improved coordination and more effective TSMO in those corridors.

To continue the emphasis on TSMO implementation, Caltrans also created a TSMO ROF website with information from all its ROFs, including information on topics such as TIM, corridor issues and challenges, planning and programming for operations, work zones, safety, freight and connected vehicles, and CMM self-evaluation.⁽⁴³⁾

Effective Practice: Plan for Operations

Developing robust practices to include operational strategies in planning and programming processes is another method to ensure a successful TMS rollout. WSDOT implemented and expanded its TMS on I-5, State Route 520, and I-90 within the last couple of decades.⁽⁴⁴⁾ WSDOT deployed a variety of operational strategies, including adaptive ramp metering, dynamic lane use control (DLUC), dynamic shoulder lanes, dynamic speed limits, and queue warning. WSDOT intended these various deployments to reduce crashes, improve travel time, and improve travel time reliability. Its DLUC operational strategy, for example, includes VSLs and lane status information to warn drivers of downstream backups as they approach significant congestion, a lane-blocking incident, or a work zone.

WSDOT successfully implemented this substantial set of operational strategies by making active management a priority in business processes such as planning and budgeting. Including the enhancements to WSDOT's TMS into the traditional planning process within the context of regional goals helped to secure funding for the project.

In general, agencies can incorporate operational strategies and the development of new or improved TMSs by widely distributing basic concepts about the TMSs and their operational scenarios and explaining the benefits of deploying such systems. During the feasibility study for its I-5 ATM deployment, WSDOT engaged representatives from FHWA, Washington State Patrol, Puget Sound Regional Council, elected officials, decisionmakers, and local agencies in workshops and forums to spread information about the system and gain support for the development and implementation of the system.⁽⁴⁴⁾

Assessing the Capabilities of a TMS

When planning a new TMS, or improving, upgrading, or replacing an existing TMS, agencies first conduct feasibility studies either for the system or for specific components. Feasibility studies include several steps as follows:

- Improving, revising, replacing, or planning a new system could apply to any system component and does not necessarily mean that the entire system be enhanced at once. A feasibility study can be conducted on an entire system or just the proposed enhancements or expansion of the existing system. Agencies may elect not to deploy an entire new system due to constraints such as lack of resources or may elect to pilot a new function along a specific corridor, road facility, or district. Recognizing that specific components of a TMS can be enhanced to gain adequate benefits allows for an agency to improve incrementally and at a pace that is feasible.
- Implementing a TMS or updating specific components of a TMS includes budgeting for the effort and planning for interoperability with existing systems. Specific aspects of a TMS upgrade could include updating software platforms, computing platforms, data management subsystems, user interfaces, and field components; expanding areas of service; enhancing the operational strategies, services, or functions of the system; and other possibilities. Agencies consider these requirements when implementing these changes in a feasibility study.
- Enhancing or expanding an agency's current TMS operational strategies or functions, or implementing a new TMS, involves a planning process. A feasibility study or assessment is completed as part of, or in parallel with, the planning process and completed before agencies move forward with the development of the TMS concept. Agencies dive into the risks associated with performing these enhancements and improvements, meeting with various stakeholders to fully understand needs and sketching out a rough system design to identify challenges as well as proposed benefits. Considering the rapid pace of technology advancements and the associated impacts on TMSs, understanding what factors drive the risk and feasibility of a TMS project and how that viability may change in the future is imperative.

Planning a TMS to address current needs and future functions, within the context of addressing congestion issues as part of the congestion management plan, can help agencies focus on the strategic planning of a TMS. Agencies that take into consideration the goals, objectives, and operational strategies developed as part of the congestion management plan, which targets improving systemwide performance and reliability, could gain more effective allocation of limited transportation funding to apply toward a TMS plan that is integrated with the broader agency and regional plans.

The integration of TMS planning also can be included as part of an MTP and TIP for an MPO, or as part of a TSMO plan, as mentioned earlier in this section. Integrated planning processes might often require a slightly different focus and applicable level of detail to describe the influence of the TMS to enable the wide range of operational strategies and services the TMS may be expected to support. In some cases, the plan may only be a description of the TMS, listing its capabilities, noting the operational strategies that would be provided, and identifying the resources needed over a planning horizon to enable the TMS to operate in that environment. By providing this planning information within an integrated plan, support placeholders can be identified early to ensure effective TMS implementation, including any necessary operations staff and funding needed to move forward.

As transportation issues continue to arise, the importance of addressing these issues at the institutional and programmatic level has become clearer. Tools are available to help agencies address these issues and assess their readiness to make improvements. Common examples of these tools are the CMM process and the CMF tool—both of which are frequently used in the planning process to help agencies assess their capability to deploy TMSs at a more formal and programmatic level.

Transportation agencies adopted the CMM as a process to increase the effectiveness of TSMO at the programmatic level.⁽⁴⁵⁾ Based on the CMM approach, the research team developed the CMF tool to assist transportation agencies as they self-evaluate their organizations' current transportation operations and management processes concerning specific operational strategies or bundles of strategies. The CMM process and the CMF tool can be used to assess an agency's current TMS operations and identify areas of improvement regarding program effectiveness.

Additionally, the CMM and CMF can help guide the development of institutional architectures into a more formal program to support TMSs and help agencies address the nontechnological challenges in developing a program centered on actively managed TMSs and help with the adoption of these systems. This support is valuable during the planning and assessment stages, so that agencies can embark on the usually longer term process of ensuring they have adequate resources available to deliver the performance and capabilities needed for the areas their TMSs are expected to actively manage.

No CMF specifically addresses TMSs, but models that cover the important policies, procedures, and general support for using operational strategies that make up a TMS are available. The information captured in this report provides an overview of the type of issues to assess for a TMS if an agency were to begin assessing its TMS.

Using Modeling and Analysis Tools

Modeling and analysis tools can be used during the planning phases of developing a TMS. These tools can provide insights into the mobility impacts of different approaches, and planners can use a variety of modeling tools to simulate various TMSs and operational strategies. Tools can be categorized as microscopic, mesoscopic, or macroscopic, depending on the type of TMS and the scale of impacts desired to be simulated.

While many challenges, gaps, and issues in linking planning and operations may occur when using analysis tools and methods, opportunities to use the existing tools more innovatively to help simulate different types of TMSs are available. Safety impacts, environmental impacts, and benefit–cost analyses are all considerations for planning a TMS that typical traffic modeling tools may not incorporate in a straightforward manner. For example, a safety analysis can be completed by using crash and incident data. However, crash reports and incident data typically lack location-specific information with enough fidelity to be useful for evaluating many TMSs, making a safety analysis a challenging task.

The environmental impacts of a TMS can be assessed by using EPA's emissions rate software MOBILE or other models such as MOVES.⁽²³⁾ Conducting a benefit–cost analysis enables an agency to consider the financial perspective of implementing a TMS. FHWA has developed

TOPS-BC to help users estimate the costs and benefits of implementing various TSMO strategies that include operational strategies deployed by TMSs.⁽²⁴⁾ The BCA.Net is a browser-based benefit–cost analysis tool that uses FHWA’s Highway Project Benefit-Cost Analysis System.⁽²⁵⁾ The FHWA Traffic Analysis Toolbox provides additional guidance on analysis methods that help agencies select the most appropriate tool(s) for their planning needs in analyzing various TMS-deployed operational strategies, such as ramp metering, traffic signal coordination, and TIM, to name a few.⁽²⁶⁾

Developing a TMS Plan

An agency can use a TMS business plan or implementation plan as a roadmap to follow to establish and link the agency’s strategic direction, vision, and goals to the TMS. Planning documents—such as the regional ITS architecture, TSMO strategic plan, ConOps, and operations plan—provide valuable input into an agency’s TMS plan. One of the greatest benefits of this exercise is its role in linking ITS programs to regional objectives and funding sources. The contents of a TMS business or implementation plan may vary slightly from agency to agency, but the plan includes five core components:

TMS Business Plan Must-Knows:

- Existing and desired functions and services.
- Actions and activities required to achieve the vision.
- Anticipated benefits.
- Roles and responsibilities of partner agencies.
- Budget for capital expenses and operations and management costs.

- **The Business Concept.** This concept outlines both existing and desired functions and services of the TMS at a high level, including the TMS’s relationships (both technical and institutional), its role in the regional context, its operational objectives, and its goals, and it presents the overall vision for the TMS.
- **Sets of Strategies.** These strategies define the actions and activities required to achieve the vision of the TMS, which could include implementations of new systems, upgrades or enhancements to existing systems, and integration activities. Additionally, these sets of strategies identify the implementation timeframe and responsibilities related to these actions.
- **Value Proposition and Benefit.** This component outlines the anticipated benefits resulting from the achievement of the goals and objectives identified in the business concept. This component is critical for the TMC plan for garnering support from key decisionmakers, leaders, and partnering agencies.
- **Organization and Management Structure.** This component defines the roles and responsibilities of partner agencies. This step includes identifying owners, managers, and participants in TMS activities and operations. Furthermore, the organization of the TMC is documented, including personnel and staffing. The TMS’s relationship to other agencies is defined here as well as relationships within the agency that owns it.

- **Financial Plan and Funding Strategy.** This strategy covers the budget for capital expenses and operations and management costs for the TMS. This plan includes the discussion of timeframes for expenditures, potential funding sources, and strategies for working within regional funding and programming processes. Procurement issues and requirements are also covered by this component.

Business Processes To Consider When Planning for a TMS

When developing a TMS plan, identifying whether a system already exists that relates to the system planning goals and objectives is important, and if a system is already in place, what components may be available from the original design that the plan can build or improve on. The TMS plan can be used to align with other agency plans, such as an MTP or a TSMO plan, and build from already-established regional transportation goals, investment and funding packages, and stakeholder relationships.

High-Level Issues To Consider

A few high-level issues to consider when planning for a TMS are institutional policies, regulations, and the feasibility of increasing operations personnel. Identifying and resolving these issues before taking the next step toward designing the system is important. The stakeholder engagement activities around the preparation of the ConOps document during systems engineering are an appropriate place to uncover and develop consensus on any future challenges that arise implementing the TMS.

Legal issues pose potential challenges to planning TMSs or operational strategies. For example, VSL may have legal and enforcement implications. When implementing a variable speed display subsystem, the agency refers to the laws and policies within the region and their impact on the operation of the agency's strategy. In the case of VSLs, the agency assesses the legal authority to establish and enforce VSLs and the willingness of enforcement entities to support the subsystem. Policies and regulations vary by location and can impact the operations of a VSL subsystem. If VSLs are not allowed in a State, a variable speed advisory subsystem may be equally effective.

The complex nature of actively operating TMSs may pose as an additional challenge to implementing TMSs or subsystems. Agencies may need additional staffing to ensure successful implementation of a TMS or an operational strategy. One example of this need can be seen in the operations of dynamic part-time shoulder use. Additional law enforcement and patrol vehicles may be used to ensure timely incident response and verification when the shoulder lane is open to traffic. Furthermore, additional operators and staff are needed to monitor the facility (usually by using CCTV cameras) to ensure that the part-time shoulder lane is free of blockages from incidents and debris that impact the performance of the system.

PLANNING AND THE CONOPS

The relationship of the ConOps and the larger strategic and feasibility planning is twofold or cyclical. The ConOps fits in both as a source to the larger planning process and a recipient of the larger planning process outcomes. While the previous section described the agency planning processes and what agencies consider when planning for TMSs, this section takes that information and discusses how these larger overall planning processes impact the ConOps and are impacted by the ConOps.

This section discusses how transportation planners look to the future by examining trends, needs, and present capabilities and how the ConOps is a source of these issues. Similarly, it discusses how the TMS ConOps provides insight into current regional capabilities, needs, and a subset of regional transportation actors' goals and objectives. It also addresses user needs and the value this assessment brings to planners. From the perspective of the TMS ConOps developer, this section discusses how planners and their documents provide many things for the ConOps—primarily, knowledge into regional players and regional prioritization of goals as expressed either explicitly through statements of strategy or program, or implicitly, through the expression of relative allocation of fiscal resources.

The ConOps is a recipient in the planning process as well as a source of input for the documents that guide it. As discussed in detail in chapter 3, the ConOps is project specific. It is a document that falls from a feasible project or regional concept, which is discussed in more detail in the following chapter.

During a comprehensive assessment that is performed for a specific project, lessons are learned with respect to the needs for a NextGen TMS. These lessons may likely be related to the goals and objectives that can in fact trickle backup to long-range planning. The ConOps reflects goals stated in larger agency-level plans as described previously, specifically, the TMS goals, vision, and functionality. The development of a ConOps and the larger, higher level plans are closely connected, as described in table 4.

Table 4. Relationship between the ConOps and agency planning documents.

| Plan | Plan Feeds ConOps | ConOps Feeds Plan |
|------------------------------|---|---|
| ITS and TSMO strategic plans | <ul style="list-style-type: none"> • Provides overarching agency goals and objectives. The ConOps can use the overarching agency’s vision and mission in general, or it can draw from specific information concerning a single function of the TMS. For example, an agency might express its objective to ensure safety across the network; and the ConOps for a TMS within the agency’s operating jurisdiction will need to align its safety objectives with the agency’s. Within the ConOps, this objective can be further reflected in the user needs, (e.g., “The user needs to detect queued traffic”) and operational scenarios, (e.g., “Incident in freeway lanes”). • Provides agency functional and geographic scope—Overarching agency strategic plans can provide a TMS ConOps with the primary boundaries, functionally and physically, within the overarching agency’s jurisdiction. | <ul style="list-style-type: none"> • Provides functional scope, mission, and activities—Agency strategic planners can use the TMS ConOps as one of many references to inform their plan relative to the transportation capabilities within a region. • Contains information regarding regional capital and operational policies and needs—For example, as TMS staff identify infrastructure needs or operational policies because of day-to-day operations, these lessons learned can be routed back to strategic planners to inform strategic thinking. • Educates and informs planners and policymakers on the role and benefits of a TMS—The high-level description of system goals, functionality, and operations along with the outcomes of a ConOps document will convey important information concerning the TMS to decisionmakers at the agency level. |

| Plan | Plan Feeds ConOps | ConOps Feeds Plan |
|----------------------|--|--|
| | <ul style="list-style-type: none"> • Provides upper-level stakeholder identification—These plans will help agencies identify who has a stake in the system at the agency level. Although all stakeholders will not be identified at this step because all stakeholders are not at the agency level, the clear interagency relationships that exist before developing the system will be influential during the development process. | |
| Agency program plans | <ul style="list-style-type: none"> • Contains features similar to the features in the agency strategic plans (identified in the first row): <ul style="list-style-type: none"> ○ Provides overarching institutional goals and objectives. ○ Provides agency functional and geographic scope. ○ Provides upper level stakeholder identification. • Describes functional constraints through a clearly defined budget—Program plans help to illustrate what programs get what funding. Therefore, a developing TMS ConOps may be able to estimate the extent of its future functional capability by examining a program plan’s budgetary disbursement. | <ul style="list-style-type: none"> • Provides features similar to the features in the agency strategic plans (as identified in the first row): <ul style="list-style-type: none"> ○ Conveys an understanding of regional, functional scope, mission, and activities. ○ Provides regional capital and operational policies and needs. |

| Plan | Plan Feeds ConOps | ConOps Feeds Plan |
|---|---|--|
| | <ul style="list-style-type: none"> • Outlines a plan for large-scale future investments—Program plans will identify and program large-scale transportation projects that can be sources of funding for future or existing TMSs. For example, enhancements to a TMS may be tied to major capital reconstruction projects of a regional freeway. | <ul style="list-style-type: none"> • Conveys needs related to infrastructure and facilities—The TMS ConOps will be able to convey information about the needs of the facilities that will be included in the capital improvements program in each applicable MPO and the rest of the State. Information provided in the system’s overview, such as system components, relationships, etc., can quickly convey the extent of such facilities. • Identifies needed TMS capital investment—A TMS ConOps will provide goals and objectives as well as a needs analysis for the current state of transportation management. This information will provide the program plan with specific uses and needs for the funding at the TMS level. |
| <p>Regional operations plans: ITS architecture—explain physical, logical, and functional relationships between the information system components that support contemporary transportation facilities.</p> | <ul style="list-style-type: none"> • Provides functionally oriented technological component identification—ITS architecture, as identified by the national ITS architecture, or the State-level ITS architecture will identify the appropriate mechanisms for the developing TMS ConOps that may be fiscally supported through federally or State-sponsored TMS infrastructure procurement and deployment. | <p>Conveys additional functional scenario development opportunities—Operational concepts identified in national and State ITS architectures may provide additional elucidation into the development of new internal functions or relationships by assisting in scenario development or assuring system robustness.</p> |

| Plan | Plan Feeds ConOps | ConOps Feeds Plan |
|-----------------|---|---|
| | <ul style="list-style-type: none"> • Provides additional insight into stakeholder identification—ITS architecture-identified functions already may be performed in a region, reducing the need for TMS ConOps to technically integrate those capabilities and look toward coordination instead. • Conveys additional functional scenario development opportunity—Operational concepts identified in national and State ITS architectures may provide additional elucidation into the development of new internal functions or relationships by assisting in scenario development or assuring system robustness. | |
| Regional ConOps | <ul style="list-style-type: none"> • Provides a functionally oriented regional collaborative common objective—The regional ConOps tends to be multijurisdictional and collaborative in nature, pooling the resources from many jurisdictions to address select transportation issues common to the region. The regional ConOps therefore identifies an objective relative to the function it seeks to address. Agencies can review the objectives in a regional ConOps and incorporate them into a TMS ConOps. | Conveys a more detailed look at a system that is part of regional operations—For a regional ConOps to provide a clear and cohesive look at regional transportation operations, a concise definition of a TMS within that region is necessary. A ConOps provides this information for a TMS, which agencies will then use to form a holistic view of regional transportation operations. |

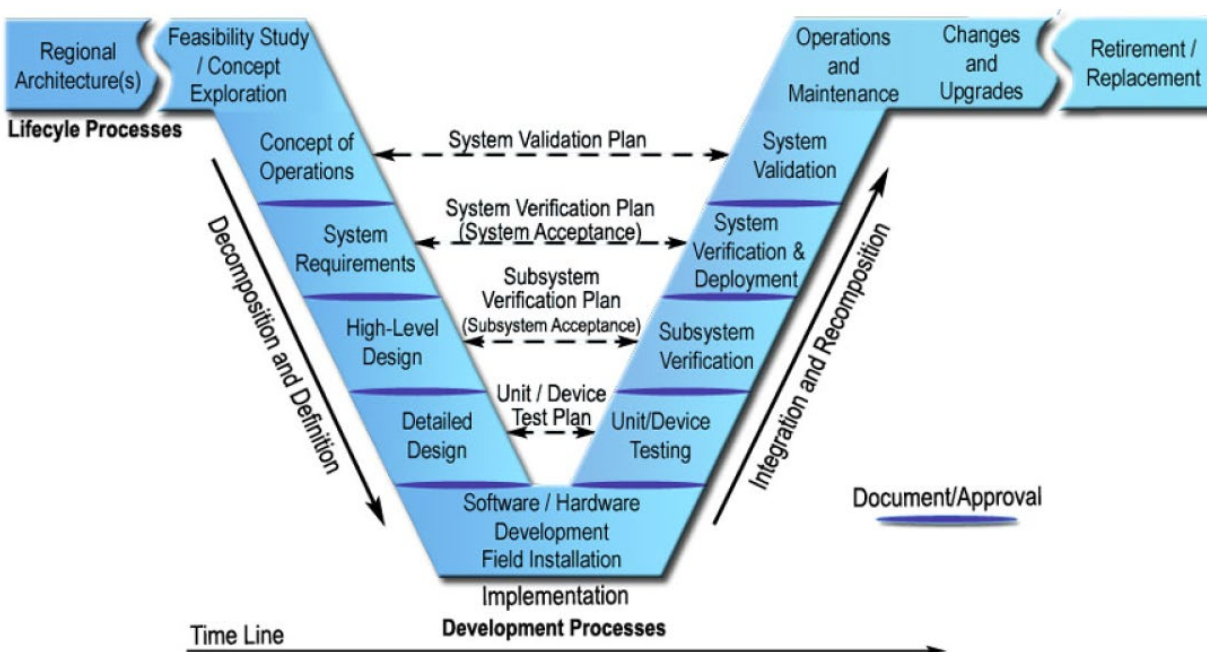
| Plan | Plan Feeds ConOps | ConOps Feeds Plan |
|------|--|-------------------|
| | <ul style="list-style-type: none"> • Identifies equipment, technology, facilities, people, and systems needed to achieve the objective—Like the common objective, the physical features necessary to accomplish the objective are identified. An agency could use the identifiers in a developing TMS ConOps as a list of features it requires to enhance the regional ConOps mission. • Provides a list of regional transportation stakeholders associated with their functions—The TMS ConOps could benefit substantially from such a list; functions of regional actors are identified irrespective of their jurisdiction. • Identifies regional ConOps participant stakeholders’ funding and other resources—Like the identified list in the previous bullet, regional transportation actors are listed by function and coupled with their financial and human resources, which is another potentially useful feature in understanding the jurisdictional focus on select transportation capabilities. Relative to the TMS ConOps, this approach will be useful in optimizing each agency’s own capabilities. | |

| Plan | Plan Feeds ConOps | ConOps Feeds Plan |
|------|---|-------------------|
| | <ul style="list-style-type: none"> • Provides additional insight into ConOps development—The regional ConOps may serve as a guide to developing or revising a TMS ConOps, specifically about detailed scenarios and user-oriented descriptions. • Describes the regional environment—The regional ConOps helps to define the overarching operational environment that the TMS, as a subcomponent to the regional ConOps, exists within. | |

As detailed in chapter 1, What is a ConOps and Requirements for a TMS?, the development of a TMS ConOps involves the review of plans and planning procedures at a higher level. This review enables longer range agency strategic plans and program plans for insight into overall goals, functionality, objectives, etc., from the stakeholder and regional levels.

CHAPTER 5. THE CONOPS AND PROJECT DEVELOPMENT

The chapter discusses the next level down from the larger agency and regional planning processes described in chapter 4. It addresses how more detailed identification of projects is derived from the larger planning process, and it covers the project-specific feasibility planning and the development of a specific project from which the ConOps is derived. In terms of the traditional project design process, the TMS development pulls from several sequential steps, each with its own slight variation. As the standard V diagram illustrates (figure 13), transportation planning; programming, budgeting, and project initiation; and preliminary engineering have become standard practices. These critical steps are discussed in this chapter with regard to their relationship to a ConOps.



Source: FHWA.

Figure 13. Diagram. Systems engineering V diagram.^(5,15)

PROJECT DEFINITION

An understanding of the project lifecycle and the predecessors of the ConOps in the V diagram is necessary for the proper development of and use of a ConOps and the requirements for a TMS. This section provides an overview of the development lifecycle following the project definition and feasibility. It pays specific attention to the systems engineering process and the ConOps' role in that process. This section also introduces requirements and their roles, but it references the more detailed look at the ConOps and requirements relationship described in chapter 7.

DEVELOPING A TMS PROJECT

After a TMS plan is in place, the next step is to develop a project or set of projects to implement the plan. Specific steps in developing a project or set of projects are needed to further develop what the system does and how it performs. Project development includes the systems engineering process, including developing the concept of the system, identifying the system requirements, and establishing the design process. Project development also includes obtaining the resources needed to design, develop, implement, and initiate the operation of the system and pursuing a procurement method that supports the development. Agencies can refer to the planning documents, such as long-range scenario planning or previously conducted feasibility studies that may have incorporated an assessment of their current systems, covered in the previous section for guidance on the established development progression. Referring to an already-established process can help guide the development of the TMS, including recommending a path to procure physical system elements such as other subsystems and the necessary components.

Procurement methods that agencies obtain for design services may differ from those services secured for the development and deployment of ITS-based systems. Agencies have options to mix and match procurement methods. Agencies need to be aware of challenges and issues when assessing their ability to procure services, such as engineering related professional services or types of contracts or general services procurements, or to maintain components with different procurement practices. Agencies weigh the benefits of these options when making the appropriate selections for back-end software systems, including whether to use open-source or commercial off-the-shelf products or to choose a proprietary or in-house designed software package, or maybe even consider integrating aspects of both options. Procurement methods are discussed in more detail in the following section.

The Development Portion of the Systems Engineering Process

When ITS components are included in a TMS, the systems engineering process applies. The systems engineering process is best conceptualized by the V diagram, which visually addresses the lifecycle of an engineered system (figure 13). This model is one of several systems engineering models that are effective in systems engineering analysis, depending on the characteristics of the project and TMS being evaluated. Some models prove to be most effective for software or application development projects, such as the iterative or agile models.⁽⁵⁾ The following sections describe the critical steps in the systems engineering process to support project development.

Regional Architecture

For ITS-related projects, agencies develop regional ITS architectures to support the region's objectives and transportation planning. Regional ITS architectures act as a framework that outline existing and planned operational transportation systems in a particular region, how they interact with one another, and how they integrate. Regional ITS architectures enable agencies to efficiently plan for transportation systems by organizing their existing transportation operation systems at a high level, piecing together how new systems may fit in, revealing how data may flow among the different systems, identifying services those systems can provide together, and

displaying how those systems support agency goals. Many regions and agencies develop an ITS strategic plan to complement a regional ITS architecture.

The ITS strategic plan is sometimes known as the ITS deployment plan, which includes priorities and strategies regarding the research, development, and adaptation of technology-based transportation systems. The ITS architecture is developed before the TMS plan is developed and provides key inputs to the following steps of the systems engineering process and the project development process. The ITS architecture identifies regional integration needs. It indicates needed interfaces and how the target TMS operates with other systems, and it identifies standards that ensure interoperability in the design and procurement processes. The ITS architecture is especially important in allowing disparate systems from multiple systems to work together.

Feasibility Study

A feasibility study also may be undertaken before a TMS project is identified; it may be the first step in the planning process, or it may be the first step in the project development process. The feasibility study is a stand-alone document that presents a business case for the potential deployment of a TMS. This process assesses the technical, economic, and political feasibility of the TMS while presenting alternative TMS concepts that meet the project's purpose and need.

ConOps

As defined throughout this report, the ConOps describes how a system is used and identifies the fundamental needs of all stakeholders involved throughout the lifecycle of a system. It allows for stakeholders to understand how the system is to be developed, maintained, and operated. The ConOps also identifies users and system capabilities in an easy-to-understand format. Chapter 6 provides more guidance specific to a NextGen ConOps.

According to the traditional systems engineering V diagram (figure 13), the ConOps document establishes the foundation for the development and design of the TMS. This exercise must correlate with the vision, goals, and measures of this foundation. Once the ConOps document has been developed, requirements for the system are defined. The requirements lay out the groundwork for the development of the technological components of a TMS and include both functional requirements (i.e., what the system is supposed to do) and performance requirements (i.e., how well the system carries out its functions). Properly aligning the system requirements with the vision and performance measures of the TMS early in the document allows for later connectivity as agencies develop the requirements phase of the ConOps.

System Requirements

The requirements development step is important because an agency uses these requirements to communicate what the system does. Requirements serve as a reference point to verify that the system was built correctly. An additional agency requirement is the establishment of environmental and nonfunctional requirements that define under what conditions the system is required to function to meet performance goals. Requirements are discussed in much more detail in chapter 7.

High-Level Design Phase

During the high-level design phase, one key consideration designers account for is whether to purchase, reuse, or develop system software from scratch. The specific project may prefer certain off-the-shelf software or hardware to be purchased. These technology decisions may also depend on the unique aspects of the project or system. Some projects have design constraints that require use of a specific product. For example, an agency is expanding its TSP subsystem to cover more key transit corridors. The agency's current subsystem includes existing detection components that communicates with proprietary central control software to implement the TSP strategy. This specific subsystem design constraint requires the agency to purchase components that have interoperability with the central software in place. The high-level design phase results in identifying subsystem components and their relationships, describing the subsystem behavior, identifying the subsystem interfaces, defining the standards to be used, and describing the information that is managed by the subsystem, integration plans, verification plans, and subsystem acceptance plans.

When developing an active TMS, such as a variable speed display system, the system design components can be divided into two primary elements: civil and technology. Core civil design elements specific to variable speed display include overhead gantry or side-mounted signs and static signage. Other TMSs may have elements such as roadway geometry elements, pavement markings, emergency pull-off areas, and others. Core technology design elements specific to variable speed displays include the control software, detection components, CCTV cameras, communication hardware, and DMSs (to display speeds and to inform drivers why they should slow down). Other technology design elements that may be applicable to other TMSs include signal controllers, controller upgrades, access control subsystems (e.g., subsystems to prevent wrong-way movements), overhead warning beacons, and others.

As with other ITS-based systems, the communications subsystem and central equipment located at a central operations center to control the field components should be defined. Central equipment and communication components may include servers, hardware racks, local networks, and communication media that interconnect hardware components. Communication media include fiber optic cables, wireless radio links, cellular links, and other communication lines.

Detailed Design Phase

During the detailed design phase, hardware and software specialists develop the detailed design for the subsystems and components identified from the high-level design phase. The results of this phase include the design of hardware and software for the system components to support development or off-the-shelf product procurement, component verification plans, and technical review documentation. A TMS operates with high levels of automation. A critical component of the design phase is to assess the capabilities of the existing software to operate the new TMS and evaluate the potential required modifications.

After the design phases, software and hardware development take place based on the components identified in the design phases. The development may include procuring off-the-shelf items or building custom software.

Implementing a TMS

Successfully implementing or deploying a TMS depends on the design, development, testing, acceptance, and startup required leading up to this phase. Agencies have used many different project delivery methods to deploy their TMS projects. Table 5 shows examples of different project delivery methods that could be used for TMS projects.

Table 5. Project delivery methods.

| Delivery Methods | Pros | Cons |
|---------------------------------|---|--|
| DBB | This approach allows the owner to control the quality of the design and construction of the project. | This method has a longer delivery schedule than the DB approach because construction must occur after the design has been completed. |
| DB | This project is developed from the start to meet both design and budget needs. The contractor's cost and pricing are transparent. | This approach requires the expectations to be clearly communicated through an RFP. |
| Design–build–operate–maintain | This method includes integrated procurement through a single contract, therefore increasing efficiency. | For this procedure, the owner does not have as much control of the project compared to the traditional DBB method. |
| Construction management at risk | This procedure is beneficial when transportation improvements are needed in a timely manner because construction elements can be accelerated. | This method can be costly for the owner. |
| Public–private partnership | This approach provides alternative funding sources. | This approach has an expensive proposal process. |

DB = design–build; DBB = design–bid–build.

Each project delivery method has its advantages and disadvantages, and the most effective method varies with each project.

Effective Practices in Implementing TMSs

Regardless of the project delivery method, early and continuous attention to coordination, scheduling, and risk management during the implementation phase is effective practice. The following summaries discuss examples of effective practice:

- The contractor takes a lead role in fostering collaboration among the stakeholders. The project schedule reflects coordination efforts to ensure that they have high priority in the implementation process. The contractor considers forming a committee to maintain information sharing, risk management, and outreach and to resolve any issues during construction if such a committee does not already exist. Some committees may already exist, such as ITS, transportation demand management, and incident management committees that can be leveraged to facilitate coordination efforts for TMS implementation.
- Effective scheduling is critical for a successful TMS rollout. When implementing a more complex system, such as ones that deploy ATM strategies (which tend to have more civil components compared to typical ITS projects), daily operations of the existing facility can be affected by delays in the civil improvements required by the system. Effective practice for scheduling includes coordination to address issues and include systems operations and maintenance training within the schedule; develop standard operating procedures; conduct education and outreach; and perform a timely software integration into the operations (including testing, debugging, and training). For example, an agency implementing dynamic part-time shoulder use lanes may require modifications to the facility's geometric properties, pavement markings, and static signage. Delays in these changes can directly affect the agency's ability to maintain existing operation of the facility. Schedule adherence and risk monitoring are priorities when implementing solutions that are inherently more complex, such as ATM, than when implementing traditional transportation projects.
- Effective risk management practices include establishing an augmented risk regime (developing documentation that quantifies risks, ranks the probability of risk occurrence, and assesses the impact of risk occurrence); establishing a risk response plan; performing a risk analysis; and ensuring that the risk management plan is revisited and updated throughout the project implementation process.

Stakeholder Engagement During TMS Implementation

During the planning phases, stakeholder engagement and public outreach are important to educate the intended audiences on the basic concepts of a new TMS, which helps to build confidence in investments and garners support for systems implementation. Gaining stakeholder and public support helps to ensure successful TMS deployment. During TMS deployment and implementation, smaller working groups can be established to provide opportunities for input and participation and to generally keep agency stakeholders informed on progress. If involved stakeholders have a common understanding on the purposes, objectives, and benefits of a new TMS, they can do a better job of educating the public to gain support.

Effective Practice: Stakeholder Engagement

Stakeholder engagement is extremely important to ensure successful implementation of a TMS. The Wyoming DOT (WYDOT) developed a VSL subsystem along a stretch of the I-80 corridor in 2009.⁽⁴⁶⁾ This subsystem, which was implemented to address weather-related closures and to reduce speeds during inclement weather conditions, comprises cameras and road and wind

sensors to monitor visibility and weather conditions along the corridor. Additionally, a weather station is placed in the middle of the project corridor to collect atmospheric conditions data, and pavement sensors are used to monitor vehicle speeds along the highway. Operators in the TMC control the speed displayed on the VSL signs based on the visibility, surface conditions, current vehicle speeds, roadway and weather conditions reported from the detection components. Engineers and Wyoming highway patrol have the authority to lower the speed limits. To our knowledge, no requirement on how often the speeds can be changed or how long the modified speeds are displayed exists.

Stakeholder engagement and public outreach were major elements in the successful rollout of the WYDOT VSL subsystem.⁽⁴⁶⁾ WYDOT used a variety of outreach methods and communication avenues to spread information about the project ranging from press releases to frequently asked question documentation and educational videos. The agency made sure that their subsystem fit into the existing legal and policy framework relating to speed limits and enforcement. WYDOT was proactive in its engagement with policy decisionmakers and law enforcement agencies to get their support and buy-in for the authority to modify speed limits within the corridor.

Lessons Learned from TMS Implementation

In recent years, agencies that have deployed advanced TMSs have learned about the importance of sharing lessons learned. The bulleted list shows a few lessons learned from other agency TMS deployments; for additional resources documenting lessons learned, see the FHWA Office of Operations website.⁽⁴⁷⁾ The following examples of lessons learned are from agency TMS deployments:

- **Develop a strong system acceptance testing program.** Provide reassurance that existing or new TMS components will meet intended functional requirements, and for TMSs that have a software element, the system acceptance would include system support documentation.
- **Establish a clear, specific vision of the functional objectives of the TMS, and communicate that vision throughout the project.** The step is especially important when a TMS involves a partnership of agencies and other jurisdictional stakeholders to establish a clear vision and minimize potential confusion.
- **Employ strong public outreach and awareness efforts in both pre- and postimplementation.** This step primarily helps to promote the TMS and its benefits, educate travelers on the proper use of the new system, and gain public acceptance.

In 2017, the Minnesota DOT (MnDOT) developed an active queue warning subsystem along its I-94 and I-34 W corridors.⁽⁴⁸⁾ The subsystem's purpose was to detect traffic conditions that may result in higher risks of crashes. When detected, the subsystem sends warning messages to upstream drivers to increase their awareness and potentially decrease the frequency of crashes. MnDOT developed the system to interface with the existing ATM subsystems already operating within the area. Prior to full implementation, the subsystem was thoroughly tested and validated to ensure proper functioning. MnDOT also facilitated a broad range of outreach techniques, including group presentations, workshops, forums, individual meetings, advertisement,

newsletters, and emails to inform travelers and policymakers on the new subsystem. Agencies such as MnDOT with successful outreach efforts realized that messages about safety benefits resonated more than technical terminology such as speed harmonization benefits. Additionally, outreach information regarding successful implementation of related projects can lay foundation for future projects.

CHAPTER 6. DEVELOPING A CONOPS

This chapter discusses understanding how a ConOps for NextGen TMS is developed. The ConOps structure described in chapter 3 is flexible and has been adapted to the needs of countless ITS projects. The key difference between developing the ConOps for a NextGen TMS is rooted in understanding how a NextGen TMS is different from other ITS projects. Similarly to how chapter 3 discussed the key questions asked in the initial development of a ConOps, chapter 6 dives into these questions while considering the newest developments most relevant to the NextGen of an agency's TMS.

To make informed decisions, developing a ConOps is one of three critical early steps along with a clear vision and an understanding of the desired capabilities. The ConOps performs the following actions to provide the bridge between the other two steps:

- Fleshes out the vision, including by involving more stakeholders and technical input.
- Establishes the system overview and operational scenarios that lay the foundation for developing a deeper understanding of the desired capabilities reflected in the requirements.

In addition to upgrading individual systems and components through projects, the NextGen of an agency's TMS requires starting from a vision that includes placing priorities on different investments in emerging technologies; embracing innovative methods; using automated functions or tasks; actively managing and operating traffic; expanding coverage across jurisdictions, roadway classifications, and geographic areas; and integrating, sharing, and using emerging sources of data. In this way, an agency's NextGen TMS can be larger than a single project or a system ConOps. It can be developed through multiple systems of a ConOps that are closely tied together and with other policies and actions taken by an agency—all guided by the NextGen TMS vision. The Maryland State Highway Administration (MDSHA) suggested that the key difference between traditional and NextGen TMSs is that all its systems used to operate independently; however, now MDSHA is interfacing all its functions into one core system, including working toward better integration between MDSHA and local agencies to enable freeway and arterial management integration.¹ These themes are repeated in several NextGen TMSs.

The NextGen TMS ConOps also needs to focus on identifying and overcoming the challenges facing legacy TMSs, such as constrained resources and limited ability to share information. A NextGen TMS ConOps needs to address the resistance to replacing systems and strategies that are familiar and effective with ones that offer enhanced functionality but that may have hurdles such as needing different expertise, procurement methods, legal frameworks, interagency agreements, or additional IT support. A ConOps can assist agencies with preparing for additional implementation challenges for NextGen TMSs, including the need to plan, build, and run

¹FHWA. 2020. "Project Team Interview—February 2020," in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS*, White Paper Summary of Industry and Public Agency Feedback. Washington, DC: Federal Highway Administration. (Unpublished.)

systems in parallel; the need to integrate connectivity and automation in parallel; and the changes in staffing or professional-capacity needs (e.g., systems engineers, data scientists, and traffic engineers). Guidance is provided at the end of this chapter for developing a NextGen TMS that incorporates these and related issues. State-of-practice sources, including industry and public agency feedback, were extracted from workshops, interviews, and published reports.

INITIATION

This section provides insights for the initial stage of preparing a NextGen ConOps—after the vision has been established, but before the ConOps is scoped. It begins with engagement from the full stakeholder complement.

The development of TMSs and the ConOps varies depending on the characteristics of the agencies and regions developing them. Thus, the information presented herein is meant to support agencies in developing their own ConOps rather than being prescriptive. This information includes raising questions for champions and stakeholders to work through. Additionally, examples from other TMSs are included to provide food for thought.

Questions to be Answered When Beginning the NextGen TMS Development Process

This section focuses on the development process of NextGen TMS rather than on the content of NextGen TMS itself (which is addressed in subsequent sections). The process is presented through questions for agencies accompanied by advice for forming answers specific to each NextGen TMS.

Why Develop a ConOps?

A NextGen TMS ConOps includes the following benefits:

- Provides a framework and establishes parameters that save time and resources in planning, designing, and procuring the system, as well as in maintenance and future upgrades.
- Ensures expected resources and capabilities align with what is necessary to manage, operate, and maintain the currently deployed and planned future systems.
- Saves time and resources when developing, managing, operating, and maintaining TMSs.
- Provides a platform for organized and cost effective future expansions or enhancements.
- Establishes the basis for planning and developing detailed system requirements and design.

While a ConOps plays a critical foundational role in the procurement process, it can continue to provide value after the procurement and development are completed because it remains a “living” document (i.e., the ConOps can be updated based on changes in an agency’s vision or goals). A ConOps is a foundation that needs to be updated and continue to inform management decisions related to system operation, maintenance, upgrades, and ultimately decommissioning or replacement. Finally, recognizing the value of a ConOps and the larger systems engineering

process for effective lifecycle project management, FHWA has made following the systems engineering process a requirement for federally funded ITS projects.

When Is the ConOps Developed?

Creation of a ConOps ideally follows creation of a NextGen TMS vision early in the process of considering the addition, replacement, expansion, or integration of TMS elements. A ConOps also is beneficial when it follows the creation of a multiyear TMS plan that links a planned NextGen TMS to the agencies and regional strategic plans. A ConOps lays out its future evolution, proposed improvements, performance expectations, and resources needed.

Regional plans are especially important when they establish common visions despite individual agencies having unique visions, goals, objectives, politics, and budgets (a problem cited by the Port Authority of New York and New Jersey).¹ These plans can identify and set in motion consensus on and resolution of issues that may not be feasible to resolve within the duration of a ConOps. Some issues include securing ongoing funding, developing additional technical competencies within agency staff, and changing policies or regulations that would constrain envisioned NextGen TMS strategies.

Who Develops the ConOps?

As discussed in chapter 5, broad stakeholder involvement to reflect the wide spectrum of departments, agencies, and system users is a hallmark of most NextGen TMSs. The development of TMS ConOps typically requires larger than usual stakeholders. Some of those key players include State and local agencies, public safety agencies, planners, and utility contractors. Of the stakeholders, a development team, including a core group of agency management personnel who have the support of agency leadership and are closely connected with the staff operating the TMS, would take the lead role in developing the ConOps.

What Are the Challenges With Developing a ConOps?

The challenges associated with developing a ConOps generally fall within two categories:

- **Process and mindset.** These challenges are possibly high-level and often cross-cutting hindrances to the smooth and effective functioning of the ConOps development participants. Many of these challenges are related to the need for cultivating mindsets within participants who both grasp and are open to NextGen TMS changes that may be fundamentally different from previous ConOps with which they may have been involved. This section focuses on these types of challenges.

¹FHWA. 2020. "Project Team Interview—February 2020," in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

- **Content.** The stakeholder engagement activities around the preparation of the ConOps document may be the appropriate place to uncover, discuss, and reach some initial consensus on issues that are explored in greater detail through requirements development and into implementation. A major component of these issues is technical and raised in the context of the “What Technical Expertise is Needed?” section in this chapter. The section “How to Develop the Elements of the ConOps” also provides guidance on developing NextGen TMS-specific content for each chapter of a ConOps.

A prerequisite for an effective ConOps development process is an engaged group of appropriate stakeholders as part of the development team. Stakeholder identification is covered in chapter 5, and stakeholder engagement is discussed in more detail in the section, “Required Resources and Stakeholder Engagement.” The development challenges related to stakeholders primarily focus on fostering the knowledge and mindset for approaching a NextGen TMS, which may vary significantly from earlier TMS ConOps. These development challenges include the following issues:

- Considering that software is a tool within the agency or region’s staffing, policies and procedures, and that all the aspects need to align to provide the maximum effectiveness and benefits, is vital for NextGen TMSs; although TMS ConOps have frequently been oriented toward procuring software. All the items in the CMF tool for TSMO dimensions are applicable and assessable, including business processes, systems and technology, performance measurement, organization and workforce, culture, and collaboration.⁽²¹⁾
- Shifting away from agency responsibility for and control of end-to-end TMS (owning field sensors to issuing 511 alerts) and toward integrating third parties and other agencies is a major change for agencies and their staff. NextGen TMSs often include many such elements. For example, using third-party data is both a technical and an institutional challenge as several agencies expressed skepticism and uncertainty regarding such data. Agencies have experienced difficult transitions to new sources of data, especially without full control and knowledge of data reliability, validity, and methodology for data collection; however, as more agencies have gained experience with third-party data, they have expressed more confidence.¹

Another set of process challenges is how to discuss the following items and reflect the results within the ConOps structure, which was not built with these items in mind:

- How to prepare for uncertainty in future agency resources, capabilities, and priorities (especially across the larger group of agencies likely to be involved, which speaks to the importance of having a regional multiyear plan).
- How to address a transition from legacy systems.

¹FHWA. 2020. “Project Team Interview—February 2020,” in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

- How to approach the reality that consumers, third-party companies, and possibly executive leadership often drive change faster than typical agency planning and procurement processes.
- How to handle variance in risk tolerance across stakeholders.
- How NextGen TMSs are subject to, enable, and likely expand agency performance management efforts.
- How to envision a process or framework for decisions, especially for populating a decision support system, when multiple agencies are involved in real-time traffic management decisionmaking that impacts their own facilities and others.

A thorough ConOps is an investment in the future, yet it still can be difficult for the core development team and stakeholders to devote time to the ConOps process in the face of shorter term responsibilities.

Finally, developing a document that a group of stakeholders from a wide range of backgrounds can ultimately understand and use is challenging. The research team recommends including the creation of additional related documents, such as presentations and briefing materials, in the process.

What Technical Expertise Is Required?

ConOps have traditionally been the purview of a set of stakeholders from agencies and related consulting firms who are familiar with traffic operations and traffic and ITS designs. As the complexity and interconnectedness of TMSs have grown over the years, some agencies have mustered a more diverse set of technical expertise, a trend that is accelerating due to NextGen TMSs. For NextGen TMS ConOps development, technical expertise is needed on many levels, including the following situations:

- Assessing current system capabilities and limitations.
- Obtaining knowledge of what could be done based on underlying technical principles and terminology and awareness of rapidly changing markets, including trends and emerging companies or products.
- Garnering knowledge of how to implement/integrate the technology.
- Gaining insights on the implications to agencies' impacts on legacy systems, including how to transition technologies, staff, operations, and policies as well as scheduling and budgeting.
- Reviewing alternatives, including their advantages, disadvantages, and lessons learned.
- Sharing experience by serving as a bridge between operating agencies and tech companies and application developers who often have different objectives, constraints, terminology, and timelines.

- Conveying the information obtained through experience in meaningful ways to a diverse stakeholder group to enable informed decisionmaking.

The technical expertise needed varies somewhat with the vision and scope, but in general, technical expertise is needed to address the following opportunities and challenges presented by new technologies and processes:

- Finding and assessing data sources specific to agency needs.¹
- Sharing and using information generated by other systems, service providers, or third parties.
- Integrating analytics and prediction methods into the active management and operation of TMSs.
- Ensuring software compatibility and assessing risk of continued availability from vendors.
- Ensuring data security and privacy.
- Estimating needs for (and options for providing) sufficient computing power, communications, and data storage.
- Sharing and using information generated by other systems, service providers, or third parties.
- Automating the operation of TMS or specific operational strategies.
- Evaluating opportunities presented by connected autonomous vehicles, if agencies choose to collect, use, and share electronic messages with them—specifically, the range of issues involved in transitioning from traditional ITS to ITS that works with connected autonomous vehicles.
- Assessing the impacts of agencies sharing and using real-time electronic messages with automated vehicles, connected vehicles, and travelers using mobile devices.

This technical expertise could come from data scientists, dedicated systems engineers (including those who have experience with agile development), traffic engineers, software engineers, data security specialists, data visualization professionals, human factors experts, and automotive engineers. For example, Iowa DOT (IADOT) reported that basic software competencies are needed (dashboards and notifications) to quickly alert operators about network disturbances so

¹FHWA. 2020. “Project Team Interview—February 2020,” in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

that they can then alert agency officials and the traveling public.¹ While including all these professionals as stakeholders is likely impractical, agencies should seek their expertise when needed. Accessing such input could take many forms, including building stronger partnerships with experts within government outside the DOT, networking through professional societies, hiring consultants, engaging with vendors, hiring scientists and engineers or developing in-house expertise, discussing issues with peers in other agencies (informally or through a technical advisory board), seeking input from FHWA staff, and using published training and reference materials.

What Information Should be Collected or Developed Early in the ConOps Process?

- Guidance documents and reference plans, including the multiyear NextGen TMS plan (if it exists) and additional resources as described in the “ConOps Section: Referenced Documents” under the “How to Develop the Elements of the ConOps” heading in this chapter.
- An assessment of current resources available across major stakeholder agencies such as staff capabilities and the presence of champions in the agency, among its peers, in management, and in executive leadership.
- An identification and assessment of existing systems that includes the following actions:
 - Assess current performance, including performance relative to planning goals and objectives.
 - Determine what components may be available and can be upgraded.
- Institutional policies and regulations.
- Legal issues that may pose challenges to planning TMSs or operational strategies (e.g., VSLs may have legal and enforcement implications).
- A feasibility study of increasing operations personnel or significantly changing required skills or responsibilities within the time horizon of NextGen TMS implementation. The feasibility study is another item that may benefit from being advanced through a multiyear plan.

FACTORS IMPACTING THE SCOPING OF THE CONOPS

The agency or region’s NextGen TMS vision provides high-level guidance to the NextGen TMS ConOps. The NextGen TMS ConOps may take the form of a set of NextGen TMS ConOps covering parts of the vision as the agency or region transitions from what currently may be multiple disparate systems to an integrated modular and flexible NextGen TMS platform. The

¹FHWA. 2020. “Project Team Interview—February 2020,” in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

overarching philosophy that expanded collaboration across systems necessitates that each ConOps focus on a single system also needs to reflect the interconnections with other systems and the overall vision. For scoping a NextGen TMS, agencies' awareness about what technologies, data, and other drivers of change are likely to exist is important so this information can be reflected in the ConOps.

The following aspects of a particular ConOps can help give an impression of relative scope:

- Where in a system lifecycle—new system, integration into a regional system, or expansion or upgrade of an existing TMS.
- What is the operating environment—freeways, surface streets, multiple facilities, multimodal corridors, or regions.
- What is the geographic extent—single facility, single jurisdiction, multiple jurisdictions, regional or district, statewide, multi-State, or multinational.
- How many agencies—single agency, multiple transportation agencies, multiple agencies, and disciplines; are additional brick-and-mortar TMC facilities needed or are existing facilities and a virtual presence enough.

A ConOps that includes transitioning the backbone of a legacy TMS to a NextGen TMS presents the most significant technical and operational changes, yet it also offers the most benefits for a region that already has a TMS. While the ultimate decision about whether an existing TMS software can be modified versus replaced becomes clear through the ConOps and requirements or capabilities development processes, an early understanding of how flexible legacy systems are is useful, both technologically (what standards-based interfaces they have) and contractually (how amenable legacy vendors are to integration with other systems (IOS) and custom development). The broader the operating environment, the larger the geographic extent, and the higher number of agencies involved, the greater the ConOps scope.

Additionally, a larger ConOps scope yields larger potential benefits by leveraging the collaborative systems to improve transportation management for more travelers. Because ConOps also are typically a step between a fiscally unconstrained vision and a funded project, the scope's major aspects also reflect a first cut at a feasible undertaking.

HOW TO DEVELOP THE ELEMENTS OF THE CONOPS

This section, which builds on the list of standard elements of a ConOps discussed in chapter 3, focuses on developing content specific to NextGen TMSs.

ConOps Section: Scope

This section of a ConOps provides an overview of the document, which is not significantly different to prepare than for a typical ConOps. The NextGen aspects of the overall ConOps are reflected in this section.

One item not explicitly covered elsewhere that is of particular importance in the NextGen TMS is identifying the intended audience. NextGen TMSs tend to have larger stakeholder groups from more diverse organizations, so establishing the commensurate wider audience is both helpful as a reminder to ConOps developers and reviewers. Examples of these entities are atypical organizations, including third-party data providers, Web services or cloud computing groups, and freight or shipping and receiving companies.

Reassuring the wider audience who may seek out the document, including those individuals not typically involved with ConOps, that the document is meant to be accessible to them as well is also helpful. In traditional highway projects, usually single owner or single operators are responsible stakeholders. However, when compared to a TMC that consists of multiple agencies, owners, operators, and maintainers can range from first responders to government officials to third-party telecommunication groups. The workforce for a traditional isolated transportation infrastructure-based project differs greatly when compared to a labor force repairing a bridge or road because different participants are involved. The projects are supported by different stakeholders, and the users' roles vary as well.

Also, given the importance of vision in NextGen TMS, this section is an early opportunity to summarize the vision clearly, including excerpting from existing NextGen vision documents. Although the research team recommends establishing a multiyear vision before the ConOps effort. If such an effort has not been undertaken, then visioning, which is documented in this section, should be conducted as early as possible in the ConOps process.

ConOps Section: Referenced Documents

Collecting reference documents to draw from when developing the ConOps reflects the wider array of stakeholders and technical topic areas found in NextGen TMSs. Refer to and build off (when appropriate) existing TMS designs, feasibility studies, and plans (e.g., architecture, vision, ConOps, requirements). Include the region's and agency's strategic plans, TSMO plans, and long-range transportation plans to ensure that the ConOps concepts, scenarios, and use cases align with those plans, including that the planned system supports current and future capabilities. Incorporate current TMS performance, capability assessment, and identified needs. Leverage and preserve institutional knowledge—be sure to learn from the past in building the NextGen.

ConOps Section: User-Oriented Operational Description

One of the benefits of NextGen TMSs is that they enable a wider array of users to access useful data (often that have been processed into useful information). NextGen TMSs also rely on a wider array of users contributing data. This section of the ConOps is intended to capture the system from the perspectives of all users. Examples of users and perspectives to be covered in user-oriented operational descriptions include traffic engineers, data scientists, and partners in third-party companies who contribute data to agencies or provide information to travelers.

NextGen TMSs thrive with involvement from both public and private entities. The NextGen TMS considers the current roles and responsibilities of stakeholders and their respective users as well as how these stakeholders and users are intended to change under the NextGen TMS covered by the ConOps to the desired state. Given the pace of change, especially among private

data providers and those providers who reach travelers, understanding the flexibility to accommodate changes is important.

Another important aspect of the user-oriented operational description to consider is automating the operation of a TMS or the specific operational strategies. Input from stakeholders includes the areas they would find beneficial to automate and what impediments exist to doing so. This understanding facilitates the development of recommendations to include in the ConOps that all involved stakeholders support and guide requirements development accordingly.

IADOT currently is working toward a streamlined interface for operators, which is an area of opportunity for NextGen TMSs.¹ While IADOT already uses a decision support subsystem that has an embedded data fusion tool, operators are still required to enter the same data into multiple systems. Streamlining would improve the agency's TMS capabilities and efficiencies. Similarly, the Ohio DOT is pursuing a NextGen TMS that includes automatically generating data summaries developed from multiple sources of data into a format that makes it quicker and easier for operators to use to generate traveler alerts.⁽⁴⁹⁾

Because the functioning of a NextGen TMS often entails the coordinated functioning of users from various departments within and across agencies, the ConOps also can provide the valuable service of developing and documenting roles and responsibilities. For example, the GDOT-led RTOP ConOps includes an extensive table of responsibilities with rows of areas (such as system maintenance—issue reporting, tracking, and management) and columns of various parties (including individuals such as the program management personnel and more generally such as the local agency officials).⁽³⁶⁾

ConOps Section: User Needs

This section elaborates the needs identified through the visioning process. For a NextGen TMS, user (or operational) needs are expected to be much broader than for the traditional TMC-based TMS needs of real-time traffic management and traveler information. Rather, focus on drawing out the needs of stakeholders who may not have been previously involved in ConOps or traffic management—such as traffic planners, first responders, and telecommunication operators—who are articulating what types of data (including format and reliability) are needed for their purposes.

ConOps Section: System Overview

The perspective of this section of the ConOps on the proposed system is a high-level description of the interrelationships of key system components. Because a NextGen TMS is often a system of systems, these connections are essential to conceptualize in the ConOps so they can be further developed in the project's requirements. This section introduces the relationship of the subject ConOps to other existing and planned systems that are outside the current scope except for the interfaces among them. The system overview is derived from the vision, focusing on the

¹FHWA. 2020. "Project Team Interview—February 2020," in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

interconnections of the systems and strategies so that they can be integrated to perform the system functions and meet the goals and objectives.

The following list of NextGen TMS operational strategies can serve as a catalyst for potentially included systems:

- System monitoring and active management—network surveillance and detection, active management.
- System management and traffic control—ramp metering, managed lanes, traffic signal control, VSL and display, speed warning, queue warning, signal priority and preemption control, lane use control and reversible lane control, hard shoulder running and part-time shoulder use, roadway closure management, and parking management.
- Incident and event management—TIM, emergency management, special event traffic management, and work zone management.
- Information dissemination—traveler information and situational awareness across agencies.
- Data collection and management—road weather information, data management, and weigh-in-motion statistics.

Although the system overview has typically been a high-level description, given the complexities of system interconnection in NextGen TMS, additional attention given to identifying the interconnections is important so that initial technological and institutional challenges can be documented. While engaging stakeholders on the system overview, inquiring about their current practices; lessons learned; and plans for system integration and data collection, archiving, sharing, and use across different stakeholders can be useful.

ConOps Sections: Operational and Support Environments

In the context of a ConOps, the operational environment refers to the context of a “world” in which the system operates, including the “facilities, equipment, hardware, software, personnel, and operational procedures.”¹ These items are discussed together because they are all closely related to the support necessary for operating the system throughout its lifecycle. A NextGen TMS is a system comprising a complex, integrated blend of hardware, software, processes, and people performing a range of functions and actions. As a result, a NextGen TMS ConOps likely has a more extensive operational environment chapter than may be typical for a legacy TMS.

Several items related to operational and support environments discussed in the “What information should be collected or developed early in the ConOps process?” section are

¹FHWA. 2020. “Project Team Interview—February 2020,” in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

documented in this chapter of the ConOps. These items include assessing existing systems as well as the current and expected future agency resources and capabilities.

NextGen TMSs do not necessarily add or remove staff, but roles are likely to change. NextGen TMSs typically include networking systems, automation, and predictive capabilities to enable the reallocation of TMC operator time from rote actions to more complex analysis and decisionmaking, which can include collaborating across agencies and modes on situational awareness and proactive coordinated responses to unfolding transportation conditions. New tasks also can require TMC operators, supervisors, and management personnel to interface with other disciplines such as traffic engineers, planning personnel, and data scientists.

For example, the Port Authority of New York and New Jersey’s Agency Operations Center leveraged its 24 h a day, 7 d a week operator staff to observe driver behavior in response to major changes stemming from conversion to all electronic tolling.¹ As the roles and responsibilities of TMC staff evolve under a NextGen TMS, the staff members’ required knowledge, skills, and abilities also keep pace. These changes likely require corresponding changes to job descriptions, compensation, and training, regardless of whether the TMC staff are agency employees or consultants. An agency’s decision to use internal staff or consultants is not significantly affected by a change to a NextGen TMS unless civil service or other agency constraints are a significant hindrance to timely modification of positions, or some specific technical services are not needed on a full-time basis and can be provided through an oncall contract.

Another consideration is identifying major constraints of the environment in the ConOps to support appropriate requirements developments. For example, TxDOT found that its business network includes firewalls and other cybersecurity protections that pose a challenge to the NextGen sharing of data with other systems, agencies, and stakeholders. As a result, the TxDOT intends to establish a network specifically for these types of data sharing.¹

Capabilities, capacity, risk tolerance, and resources vary across agencies and likely vary over the time horizon of the TMS being described by the ConOps. Agencies should be realistic about the trajectories and build in flexibility.

ConOps Section: Operational Scenarios

Operational scenarios are not significantly different for NextGen TMS ConOps than for typical TMS ConOps. However, given the wider range of stakeholders and interconnectedness of systems, a greater number and variety of operational scenarios are likely necessary. The following examples highlight potential operational scenarios:

¹FHWA. 2020. “Project Team Interview—February 2020,” in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

- Identifying, collecting, storing, sharing, and using data for integrating TMS data with police crash records to create a correlated dataset that can answer questions such as how TIM component response times correlate to crash severity.
- Reflecting an initiative that the Port Authority of New York and New Jersey is working on now by creating a feedback loop for major construction lane closures that includes TMC operators documenting actual volumes, delays, and queues during the exact times that a lane closure is in place. Comparing those observations to the modeled values thereof that were used to inform the decision of the lane closure hours; comparing the prediction to the observed; and then using the results of the comparison to refine future modeling. The feedback loop approach would yield more accurate predictions and result in more effective decisionmaking than the model approach.

In both examples, a need is developed into an operational scenario with enough detail to begin identifying the data needs, stakeholders, data processing, and technical expertise that are needed as the project advances toward a successful implementation of the scenarios.

REQUIRED RESOURCES AND STAKEHOLDER ENGAGEMENT

Developing a ConOps is an investment in the quality of the resulting TMS. The resources required, including the time of stakeholders to be engaged, are not universal, but instead depend on the size and scope of the system. By the nature of a NextGen TMS tending to encompass more systems and stakeholders, a NextGen TMS ConOps developed by agencies is likely to be more extensive and require more resources than those efforts an agency may have undertaken for previous ConOps developments.

Before a ConOps is scoped and initiated, a core group of NextGen TMS champions, comprising the primary users of the NextGen TMS, has likely been established in an agency. These staff members allocate sufficient time to be knowledgeable about NextGen TMS issues, build connections with peers inside and outside the organization who also are interested in NextGen TMS, and discuss the potential for NextGen TMS with executives. This groundwork, occurring even before the ConOps begins, is likely to help secure the additional resources necessary for development of the ConOps, including commitments in both staff time and possible consultant support.

Outside consultants can offer input on other NextGen TMS projects, provide technical knowledge in emerging NextGen TMS areas such as data science, and spend time creating documentation to free agency staff to use their available time for agency-specific input that cannot be provided by an outside consultant. In addition, consultants can include support for graphic designs to effectively communicate information across the ConOps itself as well as related supporting materials (e.g., presentations).

Active participation among stakeholders is essential for the development of any successful ConOps. Strategies common to stakeholder engagement apply, such as securing executive-level commitment for staff involvement, emphasizing benefits and opportunities for each stakeholder from the proposed system, offering interactive sessions, and providing a combination of sufficient advance notice and backup dates for workshops that require participation from many

stakeholders. ConOps for TMSs require participation from traffic operations staff members—many of whom need to prioritize response to unplanned events over workshops. Having a backup date can help with schedule adherence when a significant portion of workshop participants need to cancel on short notice.

Although many agencies have previously relied on in-person ConOps and other workshops, the COVID-19 pandemic forced some agencies to switch to virtual events. While virtual events have potential drawbacks, such as a greater potential for distraction, NITTEC's recent experience with a NextGen TMS ConOps workshop was so positive that it considered virtual events even when health and safety considerations no longer applied. NITTEC found scheduling was easier because participants did not need to factor in travel time.⁽³⁸⁾

While both individuals and agencies are rapidly gaining experience in selecting and using online meeting platforms to foster engagement, including through breakout rooms, initial efforts may require additional planning time as well as the insights and possibly software account access of additional individuals. The rise in virtual workshops would diminish the need to postpone events due to inclement weather. However, operations staff members may still need to cancel to fulfill their responsibilities managing the traffic impacts of an inclement weather event.

NextGen TMSs have a significant benefit in drawing from a wide stakeholder group, including knowledge from many disparate groups, such as data scientists. However, that benefit relies on the ability of the various individuals effectively voicing their input and having it be understood by others. That understanding was likely not a major concern in ConOps for traditional ITS and TMSs in which most stakeholders already were quite familiar with traffic management principles and terminology as well as many of the other stakeholders and the roles of their agencies. However, for a NextGen TMS, attention is given to the following actions:

- Welcoming new stakeholders to the process (including explaining the ConOps process, providing background on existing TMS and ITS systems as well as common terminology thereof, and encouraging participation, including explaining concepts and terminology that the wider group may not know).
- Priming traffic management staff for heightened involvement from other parties (including introducing why the wider stakeholder group is beneficial and discussing the impact on roles and responsibilities from involving additional agencies and companies in the proposed TMS).

PERFORMANCE MEASUREMENT

The development of a ConOps is a natural catalyst for identifying performance metrics based on goals and needs. In addition, appropriate capabilities needs to be developed to efficiently create and share the data required to evaluate against the metrics.

As part of a performance management initiative development program, the MnDOT recently conducted a workshop process that could be adapted within a ConOps development process.¹ It convened stakeholders, including staff across the agency as well as industry experts to focus on what, why, and when (not how) of performance management. The workshop included a review of agency needs, related agency performance management initiatives, agency goals and objectives, and national best practices. A brainstorming session followed, and the agency identified individual performance metrics within a matrix of both category (mobility, traffic signals, safety, and construction) and what it provides insight into (a custom variant on outputs versus outcomes: the TMC level of activity and/or quality, direct TMC impact, and system performance (which could reflect indirect TMC impact)). For example, a safety metric of quantity of instances of TMC operators reporting patterns of near misses to the agency’s traffic engineer’s tasks with improving safety provides insight in the TMC level of activity or quality.

Another safety metric is the number of remedial actions, such as signing or striping changes, taken by traffic engineers in response to TMC reports. The metrics of crash rates (or a reduction in near misses) at the subject location of the changes provided insight into the TMS’s direct impact. The resulting list of performance metrics were then prioritized based on importance and feasibility of collecting required data. The results have provided impetus for targeted expansions of data collection and fusion efforts as well as guided the development of requirements for creation of performance management dashboards. GDOT’s NextGen TMS emphasizes performance measurement.¹ Its RTOP ConOps includes the performance measures and targets described in table 6.

Table 6. Performance measures in GDOT’s RTOP ConOps.⁽³⁶⁾

| Product | Measure | Goal |
|----------------|--|--|
| Outputs | Vehicle detection devices | >95 percent operational |
| | Pedestrian detection devices | >95 percent operational |
| | Complaint response time | <24 h |
| | Proactive identification of equipment malfunctions | >70 percent of malfunctions detected by corridor managers |
| Outcomes | Complaint response time | <24 h |
| | Travel times (twice per year per corridor) | Improvement over baseline measurement and no increase in subsequent periods |
| | Throughput | Increase in volumes less than percentage of increase in stops and delay |
| | Customer satisfaction surveys | To be determined (specific goals will be developed during survey design) |
| | Travel time reliability | To be determined |
| | Queue studies | Qualitative evaluation of the impact of the program on side street queues and delays |

¹FHWA. 2020. “Project Team Interview—February 2020,” in *Next-Generational Traffic Management Systems: Concept of Operations and Transitioning from Legacy System, Task 2: State of Practice for Developing ConOps and Requirements for TMS, White Paper Summary of Industry and Public Agency Feedback*. Washington, DC: Federal Highway Administration. (Unpublished.)

KEY REFERENCE DOCUMENTS AND WEB PAGES FOR WRITING A CONOPS

The following sources are some of the key references that can be used in a ConOps development:

- SAE EIA632: *Processes for Engineering a System*.⁽⁵⁰⁾
- SOCRATES 2.0 initiative.⁽⁵¹⁾
- Work Zone Data Exchange.⁽⁵²⁾
- *Integrating Weather in TMC Operations*.⁽⁵³⁾
- *Weather-Responsive Traffic Management Concept of Operations*.⁽³⁹⁾
- *Model Systems Engineering Documents for Adaptive Signal Control Technology Systems—Guidance Document*.⁽⁵⁴⁾
- *Integrated Corridor Management: Implementation Guide and Lessons Learned (Final Report Version 2.0)*.⁽⁵⁵⁾
- *Assessment of Emerging Opportunities for Real-Time, Multimodal Decision Support Systems in Transportation Operations—Task 4 Concept of Operations*.⁽⁵⁶⁾
- *Roles of Transportation Management Centers in Incident Management on Managed Lanes*.⁽⁵⁷⁾
- *Guidelines for Virtual Transportation Management Center Development*.⁽⁵⁸⁾

GUIDING PRINCIPLES

The ConOps is a reliable systems engineering tool for developing ITS projects and TMS programs. The ConOps is especially well suited to developing NextGen TMS because it includes tools for managing the hallmarks of how NextGen TMSs tend to differ from previous TMSs—namely, engaging a varied set of stakeholders with each other on advancing approaches to the TMS within a rapidly changing landscape of technology options. The ConOps enables the structured involvement of these stakeholders around progressing from a high-level shared vision to a firmer definition of what the resulting system achieves, thus setting a path toward a more useful system.

To help experienced practitioners of the ConOps and those new to the process to embrace the differences for a NextGen TMS ConOps, this chapter recommends that a core group of stakeholders thoughtfully answer a set of questions for the program before scoping the NextGen ConOps. These questions include why, when, and who develops the NextGen ConOps, and it defines the challenges to developing the NextGen ConOps, the technical expertise needed, and the information collected or developed early in the ConOps process. For each section of a ConOps, this chapter also offers specific insights to tailor them so they will be effective for the NextGen ConOps. Identifying performance measures also is useful for working backward from regional goals to the data generation, processing, and sharing functions that underpin various operational scenarios. This process, in turn, facilitates the development of an effective system.

CHAPTER 7. DEVELOPING AND USING TMS REQUIREMENTS

The ConOps provides the framework for development of effective system requirements, which ultimately enables effective implementation of the NextGen TMS in accordance with the regional multiyear vision. This chapter discusses how the ConOps framework—the user-oriented description of the TMS—drives the more specific definition of what and how the TMS is to perform. Given the complexity of NextGen TMS, identifying the capabilities—functions and services—to be provided to meet the TMS vision and ConOps is also helpful.

A complete ConOps that identifies user needs, key system interfaces and data needs, and performance measures ties together the human elements of the project (traveler benefits, operations, and data analysis) with the system elements (data interfaces, system functions, etc.). A well-defined ConOps bounds the project scope, which enables all parties involved to know when a requirements elaboration is complete. A complete and logically consistent set of requirements facilitates the process of developing more detailed specifications for an RFP, allowing requirements developers and project management staff to know where to start and when requirements are complete. System requirements are traced to user needs and provide a framework for system testing. System verification checks that the system owner received the system in accordance with the requirements and with the user needs articulated in the ConOps.

WHAT IS A REQUIREMENT?

In the context of systems engineering, a requirement is “a statement that identifies a necessary attribute, capability, characteristic, or quality of a system for it to have value and utility to a user” that is based on the ConOps and that must be verified or measured.⁽⁵⁹⁾ An alternate definition is “something that governs what, how well, and under what conditions a product will achieve a given purpose.”⁽⁵⁰⁾

As articulated by FHWA’s model systems engineering document, a requirements statement captures “WHAT needs to be achieved by the system. It specifically should not describe HOW the system will satisfy the needs” (see p. 13).⁽⁵⁴⁾ Rather, the statement “sets the technical scope of the system to be built” (see p. 14).⁽⁵⁴⁾ This approach preserves the flexibility for vendors to provide various approaches to achieve the same desired functionality.

Because functional requirements define what the system does, developing these requirements early in the process can help all stakeholders get a clear understanding of how the system operates in its environment. The following example shows what functional requirements can look like when developing a TMS. The MDSHA Coordinated Highway Action Response Team (CHART) manages and operates both freeway and surface street TMSs in the State. One function of its TMS is to generate reports summarizing the data collected from their subsystems. The excerpt in the following text box shows a sample of system requirements for the report generation function.⁽⁶⁰⁾

CHART II system requirements excerpt⁽⁶⁰⁾

3.1.4 Report Generation

This section lists requirements for the generation of reports from the CHART system and archive data.

3.1.4.1 The system shall provide the capability to generate reports from online and archived data.

3.1.4.2 The system shall support the generation of operational reports.

3.1.4.2.1 The system shall support the generation of a center situation reports.

3.1.4.2.2 The system shall support the generation of a disabled vehicle event report.

3.1.4.2.3 The system shall support the generation of an incident event report.

3.1.4.2.4 The system shall support the generation of traffic volume reports.

Effective requirements enable procurement of a system that meets needs. Good requirements have the following characteristics:

- Concise.
- Clear and unambiguous.
- Consistent.
- Single thought—not including multiple components separated by “and.”
- Verifiable.
- Necessary.
- Technology (vendor) independent.
- Traceable to a higher level requirement of a user-specified need or scenario.

Well-formed requirements are important because they are more likely to be understood and result in a design that fulfills the requirement as intended.

TRANSITIONING FROM A CONOPS TO REQUIREMENTS

Although the ConOps significantly fleshes out an individual project within a regional multiyear TMS vision, it neither contains sufficient detail nor is geared to express the project in ways that are necessary for procuring, developing, and testing a functional TMS. Given the complexities of NextGen TMS, revisiting capabilities is a useful step in transitioning from a ConOps to system requirements.

Capabilities are conceptually like requirements but focus on the functions and services to be provided to meet the TMS vision and ConOps. They address scenarios to be supported and provide links between the ConOps and requirements. The key capabilities play a role in the processes to plan, design, develop, or initiate a new or upgraded TMS.

Agencies that are refining capabilities and developing requirements based on the ConOps should consider the following best practices for selecting capabilities:

- Consider that how these functions and services are carried out could substantially change, although the traffic management functions and services supported by a TMS may not change in the future.
- Understand how emerging data sources, innovative methods, and new technologies could allow agencies to improve how they are managed and operated.
- Seek to develop capabilities that make information actionable.
- Keep in mind end users' expectations when developing and managing new capabilities.
- Consider what capabilities will be most useful to support total demand management.
- Look beyond the bigger technology players when identifying new capabilities because some smaller firms have useful new technologies and ideas for their application.
- Include provisions for flexibility and change management:
 - Are your architecture and designs flexible enough to accommodate future system changes and new capabilities (or constantly evolving functions and services)?
 - Do you have or want to have the ability to make changes to a TMS (e.g., software platform, databases, interfaces with internal or external devices or systems)?
 - Do you anticipate significant changes to the TMS architecture (e.g., distributed design with hubs versus central processing of data) to support the desired operation?

NextGen TMS capabilities will have the following positive results:

- Improve response actions (faster, more precisely targeted, more data driven).
- Support interoperability and connectivity between centers with related purposes.
- Are modular so the system should be easily expandable.
- Provide prescriptive (rather than just predictive) analytics.
- Improve integration of transportation and enforcement—both in terms of their responses and their data.

The following examples show more key capabilities together with the successful NextGen TMSs pursuing them:

- Software platform to monitor travel and manage traffic (STREAMS System; Australia).⁽⁶¹⁾
- Software platform and shared visualization (SunGuide System, Florida DOT (FDOT)).⁽⁶²⁾

- Advanced user interfaces (Dallas ICM Project Operator User Interface).⁽¹⁴⁾
- Shared TMS functionality and resources with multiple jurisdictions (Caltrans Corridors Program).⁽⁴¹⁾
- Traffic and emergency communications network enabling the integration and sharing of data between five TMSs (VDOT).⁽³⁵⁾
- Interstate System Traffic Operations Dashboard (Indiana DOT).⁽⁶³⁾
- Active management, automated operation, and coordinated responses to predicted and changing conditions or events (e.g., I-210 ICM Initiative, Caltrans).⁽⁶⁴⁾
- Future travel conditions predictions and implementation plans to mitigate impacts (San Diego ICM Project).⁽¹⁵⁾

Although the systems engineering process is a continuum for a project, transitions from one stage to the next can include both changes in focus and in the composition of the core team members producing the deliverables. For the requirements, both the audience and the primary authors become more technically focused than in the ConOps.

Requirements' Role in Systems Engineering

When following the traditional systems engineering V diagram, the ConOps document sets the foundation for the development and design of the TMS. This exercise ties back to the vision, goals, and measures of this foundation. Once agencies have developed the ConOps document, they can define the requirements for the system. The requirements lay out the groundwork for the development of the technological components of a TMS and include both functional requirements (i.e., what the system is supposed to do) and performance requirements (i.e., how well the system carries out its functions). Proper alignment with the vision and measures early in the document facilitates later connectivity during the requirements development phase of the ConOps.

The system design phases came after establishing the system requirements. The design phases are broken out into the high-level design phase followed by the detailed design phase, and are both critical steps in the development of an engineered system. In the high-level design phase, the overall system framework is defined, including subsystems and components. For a TMS, this step includes the process of defining software, components, and interfaces. During the detailed design phase, the specifications of the software, hardware, and communication components are defined. These specifications detail how the components are developed to meet the system requirements defined in the previous phases.

Requirements Development Process

Within the systems engineering process, agencies develop the requirements while creating the systems requirements document. The target audience for the requirements document includes technical staff, system users, and once that document is incorporated into a procurement process, system designers and vendors. Various requirements document templates typically contain some

form of introductory information (including purpose and reference documents), an overall system scope and description, the requirements themselves, and a traceability matrix. The development process often includes a workshop step to involve a wider range of stakeholders reviewing and contributing additional input.

For agencies building on a project’s ConOps and capabilities, a starting place for requirements development is to answer the following questions to envision the top level of the system (see p. 56):⁽⁵⁴⁾

- What are all the functions needed to demonstrate to the agency that the system is doing what it is expected to do?
- How well does the system need to perform the required functions?
- Under what conditions does the system need to operate?

These questions illustrate how a comprehensive set of requirements is broader than just the obvious traffic management functions of a TMS (the functional requirements). When agencies are moving into developing detailed requirements, including by drafting requirements based on each need and function in the ConOps, keeping in mind a wide range of categories of requirements, such as those shown in table 7, is helpful.

Table 7. Categorization of requirements.⁽⁵⁴⁾

| Category | Description |
|----------------------------|--|
| Functional requirements | What the system should do. |
| Performance requirements | How well it should perform. |
| Nonfunctional requirements | Under what conditions it will perform. |
| Enabling requirements | What other actions must be taken for the system to become fully operational. |
| Constraints | Limitations imposed on the design by agency’s policies and practices, such as type of software, type of equipment, and external standards. |
| Interface requirements | Definitions of the interfaces between subsystems or with external systems. |
| Data requirements | Definitions of dataflows between subsystems or with external systems. |

The requirements development step is important because an agency uses these requirements to communicate what the system does. Requirements serve as a reference point to verify that the system was built correctly. An agency also establishes environmental and nonfunctional requirements that define the conditions under which the system is required to function to meet performance goals.

Identifying system requirements can be at the discrete component level or at a higher level that can encompass certain systems, such as virtual TMSs, active TMSs, temporary TMSs, testing programs, and procedures.

For complex systems, or ones in which the market and level of effort to meet some requirements is unknown, requirements can be classified as mandatory, desirable, or optional. As reported in the *Model Systems Engineering Documents for Adaptive Signal Control Technology—Guidance Document*, “Very often, optional can be used to define requirements that will be important at a future date but need not be included in the package purchased at this time. This ensures that future system expansion and migration paths are not precluded by the initial system design and capabilities” (see p. 15).⁽⁵⁴⁾ This focus on flexibility for future expansion also resonates for NextGen TMSs.

Before concluding the requirements development process, check that all the following key elements for NextGen TMS requirements have been covered:

- Includes an overall system description.
- Is based on the operational needs identified in the ConOps.
- Extracts the requirements necessary to meet the needs.
- Includes implementation stage requirements such as for verification and validation and for agile development.
- Includes a traceability matrix that links the operational needs, performance measures, and goals to the system requirements.
- Includes a stakeholder workshop in the development process.

EXAMPLE OF GOOD REQUIREMENTS

Michigan DOT’s (MDOT’s) *Vehicle Infrastructure Integration (VII) Data Use Analysis and Processing—Project Summary Report* provides a good example of a framework for requirements as well as good requirements themselves.⁽⁶⁵⁾ The framework groups requirements by type, includes space for comments, and provides direct references to the ConOps or another document that is the source of each requirement. Table 8 through table 10 are adapted from the MDOT report and show the explanation of the requirements tables, requirement identifier (ID) format, and some sample requirements, respectively.

Table 8. Explanation of the requirements table from MDOT’s *Vehicle Infrastructure Integration (VII) Data Use Analysis and Processing—Project Summary Report* (see p. 17).⁽⁶⁵⁾

| Element | Explanation |
|-------------|--|
| ID | A unique ID used to trace requirements from beginning to end in a system development process. |
| Requirement | The text of the actual requirement. Requirements formulated with “shall” are direct requirements; those using “shall be able to” are conditioned on other requirements being fulfilled or on factors outside the control of the requirement’s subject. |
| Sources | Sources for the requirement; could be reference documents or a “parent” requirement. |

| Element | Explanation |
|----------------|--|
| Comments | Supporting text that may help explain the requirement, its importance, or the risks associated with implementing the requirement. |
| Importance | H—indicates that it is essential to the DUAP system. M—indicates that it should be implemented. L—indicates “nice to have.” D—indicates that the requirement is deferred. |

DUAP = data use analysis and processing.

Table 9. Requirement ID format from MDOT’s *Vehicle Infrastructure Integration (VII) Data Use Analysis and Processing—Project Summary Report* (see p. 17).⁽⁶⁵⁾

| Requirement ID Format | Explanation of Format |
|------------------------------|--|
| AA–NNN | High-level requirement. |
| AA–NNN–UUU | Detailed requirement. |
| AA | Represents the classification of the requirements within the requirements document. The following classifications have been used in this requirements specification: <ul style="list-style-type: none"> • IS—Input Services (Section 3.1). • AS—Administrative Services (Section 3.2). • DD—Dynamic Data Services (Section 3.3). • CS—Computational Services (Section 3.4). • PD—Persistent Data Services (Section 3.5). • OS—Output Services (Section 3.6). • PS—Presentation Services (Section 3.7). • DC—Design Constraints (Section 3.8). • QC—Quality Characteristics (Section 3.9). • XR—External Requirements (Section 3.10). |
| NNN | Represents the sequence number. Numbering is not necessarily sequential; gaps in the sequence leave room to add additional related requirements when they are discovered. |
| UUU | Provides unique identification. |

Table 10. Select requirements from MDOT’s *Vehicle Infrastructure Integration (VII) Data Use Analysis and Processing—Project Summary Report* (see pp. 18–33).⁽⁶⁶⁾

| ID | Function | Source | Comments | Importance |
|------------|---|----------------------------------|---|-------------------|
| IS-010-010 | The DUAP input services shall be able to collect probe vehicle data from the vehicle infrastructure integration proof of concept probe data device using the X-031 interface. | ConOps § 4.3.1 | The ability to collect probe vehicle data is one of the primary purposes of the DUAP project. | H |
| IS-010-030 | The DUAP input services shall be able to collect probe vehicle data from SMART Transit using the SMART Transit interface. | ConOps § 2.3.2.7 ConOps § 4.1 | The specific format of the interface is to be determined in the design of the prototype. | L |
| AS-210 | The DUAP system shall keep records of user access. | MDOT | — | H |
| CS-010-010 | The DUAP computational services shall be able to derive speed from probe vehicle data. | ConOps § 4.3.4 ConOps § 5.3 | — | H |
| OS-010-090 | The DUAP output services shall be able to publish weather data elements as enumerated in Appendix D—Weather Data Elements From Clarus—output format. | ConOps § 2.3.2.6 | See Appendix D—Weather Data Elements From Clarus—for a listing of weather data elements. | H |
| PS-050-020 | The asset condition information browser shall allow a user to view asset condition-related information using a Web browser capable of supporting HTML 4.01, JavaScript (ECMA-262 edition 3), and XML 1.0. | ConOps § 4.3.6 ConOps § 7.1 | Web browsers support these capabilities. | M |

—No Data.

HTML = HyperText Markup Language; SMART = Suburban Mobility Authority for Regional Transportation; XML = Extensible Markup Language.

The requirements document from the Spokane, WA, regional ATMS replacement project also illustrates a good framework.¹ However, the sample requirements shown in table 11 are chosen to highlight good requirements that reflect NextGen TMS aspects.

¹Parsons Brinckerhoff. 2015. *Spokane Regional Transportation Management Center—Advanced Traffic Management System Replacement—Draft Requirements Document*. Olympia, WA: Washington State Department of Transportation. (Unpublished.)

Table 11. Excerpts from *Spokane Regional Transportation Management Center—Advanced Traffic Management System Replacement—Draft Requirements Document (part 1)*.¹

| ID | ConOps Statement | Requirement |
|----------------------------------|--|--|
| TM 7 | The ATMS will have interfaces to traffic signal systems in the Spokane region. | The ATMS shall integrate with the Central Traffic Management Software Systems operated by SRTMC partner agencies to execute operations selected by ATMS operators. |
| TM 7.1 | The ATMS will have interfaces to traffic signal systems in the Spokane region. | The ATMS shall interface to exchange data with TACTICS Central Traffic Signal Control System for all intersections operated by TACTICS. |
| TM 7.1.1 | Traffic signal coordination and control (interface with TACTICS™ and CENTRACS®, interface with adaptive control). | The ATMS shall send messages to TACTICS to execute selections of ATMS authorized users related to selecting preplanned signal timings. |
| TM 7.1.2 | Traffic signal coordination and control (interface with TACTICS and CENTRACS, interface with adaptive control). | The ATMS shall receive messages from TACTICS describing confirmations of actions sent. |
| TM 7.1.3 | Traffic signal coordination and control (interface with TACTICS and CENTRACS, interface with adaptive control). | The ATMS shall receive messages from TACTICS describing traffic signal timing plans currently in operation at intersections controlled by TACTICS within the SRTMC area. |
| IEM 2.5.5 | Provide more comprehensive and up-to-date maintenance and construction activity information for any work, whether public agency or private utility, that impacts travel. | The ATMS shall include capability for operators to enter and update construction and maintenance activities for private utilities that will impact travel on public roads. |
| IOS 1 | Integrate the existing disparate systems into one integrated platform for all SRTMC activities. | The ATMS shall establish and maintain connections with existing external systems. |
| Operator and User Features 7.3.3 | Integrate incident information with maintenance and construction information. | The ATMS shall link to events that are in close proximity to enable operators to view details of related events. |
| Trav Info 5 | Consider future expansion of the SRTMC’s website to cover Post Falls, ID, and Coeur d’Alene, ID. | The ATMS shall be upward expandable to cover increased coverage areas. |

¹Parsons Brinckerhoff. 2015. *Spokane Regional Transportation Management Center—Advanced Traffic Management System Replacement—Draft Requirements Document*. Olympia, WA: Washington State Department of Transportation. (Unpublished.)

| ID | ConOps Statement | Requirement |
|-----------|--|--|
| DCA 2 | Analytics package, accessible through the ATMS with remote access, would provide users with access to the data and the ability to analyze it for a variety of purposes, including planning and performance management. | The ATMS data archive shall have an analytics package. |
| DCA 2.3 | Traffic congestion on the interstate and National Highway System. | Data analytics shall include functionality to compute and display Congestion information. |
| DCA 2.4 | Hours of congested vehicle travel. | Data analytics shall include functionality to compute and display Hours of Congested Vehicle Travel information. |
| DCA 2.5 | Travel time reliability. | Data analytics shall include functionality to compute and display Travel Time Reliability information. |

DCA = Data Collection and Archiving; IEM = Incident/Event Management; SRTMC = Spokane Regional Transportation Management Center; TM = Traffic Management; Trav Info = traveling information.

Table 12 shows how the project’s core technical stakeholders can use a ConOps statement as the basis for a series of more detailed requirements to facilitate procurement.

Table 12. Excerpts from *Spokane Regional Transportation Management Center—Advanced Traffic Management System Replacement—Draft Requirements Document (part 2)*.¹

| ID | ConOps Statement | Requirement |
|------------|---|--|
| TM 7.1.3 | Traffic signal coordination and control (interface with TACTICS and CENTRACS, interface with adaptive control). | The ATMS shall receive messages from TACTICS describing traffic signal timing plans currently in operation at intersections controlled by TACTICS within the SRTMC area. |
| TM 7.1.3.1 | — | The ATMS shall enable operators to view all parameters of traffic signal timings (i.e., not just signal timing plans) in operation that are received from TACTICS. |
| TM 7.1.3.2 | — | Information received and displayed shall include when the signal timing parameters have been overwritten, and by whom. |

¹Parsons Brinckerhoff. 2015. *Spokane Regional Transportation Management Center—Advanced Traffic Management System Replacement—Draft Requirements Document*. Olympia, WA: Washington State Department of Transportation. (Unpublished.)

| ID | ConOps Statement | Requirement |
|------------|--|--|
| TM 7.1.3.3 | — | Operators' access to signal controller parameter data received from TACTICS shall be "view only," with no control capabilities. |
| TM 12 | Develop predictive algorithm tools that use archived data to generate travel forecasts based on real-time data. | The ATMS shall include capability to generate real-time travel times. |
| TM 12.1 | — | The ATMS shall include capability to use archived data and real-time data together with predictive algorithms to generate travel forecasts for display to operators. |
| IEM 3 | Integration with enforcement CAD. | The ATMS shall include capability to receive incident reports from external systems. |
| IEM 3.1 | — | The ATMS shall include functionality to receive incidents from multiple law enforcement CAD systems. |
| IOS 5 | Integration with legacy systems, including TACTICS, CENTRACS, radio log, PeMS, and regional traveler information system. | The ATMS shall establish, maintain, and exchange data with the PeMS system. |
| IOS 5.1 | — | The ATMS shall make volume, occupancy, speed, and incident data available to PeMS through an XML interface. |

—No Data.

CAD = computer-aided dispatch; PeMS = Performance Measurement System.

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