Traffic Analysis Capability Maturity Framework

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16. Abstract
The traffic analysis capability maturity framework will assist State Departments of Transportation or regions in evaluating their current traffic analysis methods, processes, and technologies. It will suggest how these agencies could incrementally advance methods, processes, and technical approaches to better support the evaluation of traffic management strategies for freeways, arterials, and corridors. The framework will also assist in advancing to a future state of advanced analysis, modeling, and simulation to evaluate fully active and integrated transportation system management, and other emerging technologies such as connected and automated vehicles.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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LIST OF ABBREVIATIONS

AMS	analysis, modeling, and simulation
API	application programming interface
ARM	annual reliability matrix
ATDM	active transportation and demand management
ATSPM	automated traffic signal performance measures
CAV	connected and automated vehicle
CBI	congestion and bottleneck identification
CMF	capability maturity framework
CMM	capability maturity model
DMA	dynamic mobility application
DOT	department of transportation
DTA	dynamic traffic assignment
HCM	*Highway Capacity Manual*
IT	information technology
MaaS	mobility as a service
MoE	measures of effectiveness
MOU	memorandum of understanding
MPO	metropolitan planning organization
MRM	multiresolution modeling
O-D	origin-destination
SimCap	Simulation and Capacity Analysis User Group
SOP	standard operating procedure
TRB	Transportation Research Board
TSMO	transportation system management and operations
TSSM	*Transportation Systems Simulation Manual*
USDOT	U.S. Department of Transportation
VC&V	verification, calibration, and validation

CHAPTER 1. INTRODUCTION

Traffic analysis is key to developing and managing a transportation system. The entire system management cycle, from planning and design to implementation and operations, is predicated on traffic analysis that can accurately estimate the impacts on system performance. As such, traffic analysis utilization is important to support the decisions associated with various business processes of transportation agencies. Traffic analysis approaches range in complexity and capability, from simple analytical tools to advanced dynamic traffic assignment (DTA), microscopic simulation, multiresolution modeling (MRM), and agent-based simulation. Public agencies and their consultants have used traffic analysis tools, methods, and procedures, which have evolved through the years. As the complexity of the transportation system and associated decisions increase, agencies are using traffic simulation in transportation planning, design, and operations to model transportation facilities, corridors, and networks in applications that cannot be adequately modeled by analytical deterministic procedures, such as those in the *Highway Capacity Manual* (HCM) (Transportation Research Board (TRB) 2016).

However, advanced analysis, modeling, and simulation (AMS) techniques will involve capabilities and resources that are not always available to the agency. These capabilities and resources cover several dimensions with multiple levels for each dimension. The capability levels increase with the complexity of the modeling efforts the agency performs. At the same time, not all agencies require, nor can achieve, the same levels of capabilities.

The above discussion indicates the need for assessing existing agency capabilities to conduct traffic analysis in an efficient and effective manner, and for identifying courses of action to improve the capabilities based on the agency's needs, current capabilities, and available resources. The second Strategic Highway Research Program (SHRP2) reliability program developed a capability maturity model (CMM) for transportation system management and operations (TSMO) (Gregory 2012) based on a concept widely used for various information technology (IT) applications. Using the CMM, the Federal Highway Administration (FHWA) developed a number of subsequent capability maturity frameworks (CMFs) that focus on improvement actions for specific TSMO program areas, including road weather management, planned special events, traffic incident management, traffic management, traffic signal management, work zone management, and active demand management. Agencies and regions have used these frameworks to assess the current strengths and weaknesses, and to develop a targeted action plan for the program area improvement. Supporting interactive tools were also developed to facilitate the use of the CMFs. State departments of transportation (DOTs) have successfully used the frameworks to develop action plans to improve their TSMO capabilities. The TSMO CMFs will inform and provide examples for the development of the Traffic Analysis CMF in this project, as discussed next.

1.1 PURPOSE OF THE FRAMEWORK

This document provides a Traffic Analysis CMF to serve as a tool for agencies to assess their strengths and weaknesses for incorporating and mainstreaming traffic analysis activities into their business processes. This CMF will help agencies in assessing their strengths and weaknesses for incorporating traffic analysis activities into their business processes and help

them assess the recommended actions to improve their capabilities in the use of traffic analysis. This framework is not dependent upon the specific analysis tools used by the agency. Agencies can use it for different levels and purposes of the analysis, including assessing geometric improvements, signing and striping modifications, interchange modification analysis, traffic studies, signal control and timing improvements, and TSMO strategies and applications.

Applying the Traffic Analysis CMF will enable agencies to identify opportunities for improvement and develop a programmatic focus for traffic analysis to create analytical consistency and uniformity across State DOTs and Federal/regional/local transportation agencies. The CMF is applicable to agencies with different existing levels of capabilities, including agencies that have limited use of traffic analysis. The CMF will allow agencies to develop capabilities to use in assessing regular project development alternatives, such as geometric improvements or operational strategies.

The CMF will also recommend actions to improve agency capabilities to evaluate traffic management strategies. The CMF will help develop and advance the agency's analysis capabilities to more robustly evaluate advanced operational strategies and emerging technologies. The framework has flexibility to account for the needs and resources of agencies considering there is no one-size-fits-all solution.

1.2 TARGET AUDIENCE

The target audience for the Traffic Analysis CMF is State, regional, and local transportation agencies that conduct or use the results of analysis tools for transportation decisionmaking. The CMF could be useful to individual agencies, or specific departments and offices within an agency, to self-assess their current traffic analysis capabilities. The capability levels and the actions reflect the perspective of an agency or partner agencies in a State or a region. The assessment will occur at State, county, and city agencies that conduct and use results of analysis tools, including:

- AMS staff
- Planning offices
- Design and engineering offices
- Performance management staff
- Traffic studies offices
- TSMO offices
- Multimodal offices including transit, freight, pedestrian, and bicycles
- Access management offices
- Metropolitan planning organization (MPO) staff

1.3 OVERVIEW OF THE DOCUMENT

The structure of the report is as follows:

- Chapter 2 provides an overview of the developed CMF, including dimensions of the framework, capability maturity levels, and overview of the CMF steps.
- Chapter 3 provides easy-to-use tables and multiple-choice questions for a quick assessment of existing capabilities.
- Chapter 4 provides a second set of easy-to-use tables that discuss how agencies can advance to the next level, plus additional discussion of these recommended actions.
- Chapter 5 summarizes the developed CMF.

Note that the enclosed evaluation criteria and improvement actions are only suggestions and do not constitute requirements. The suggested criteria and actions may not be suitable for all agencies. Moreover, the framework does not intend to imply that it is appropriate or desirable for any given agency to pursue maximum capability across all aspects of traffic analysis. Instead, agency managers and traffic analysis stakeholder can consider which levels of capability are preferable for their own situation and then apply the framework accordingly.

CHAPTER 2. OVERVIEW OF THE CAPABILITY MATURITY FRAMEWORK

The objective of the Traffic Analysis CMF is to assist traffic engineers, planners, and traffic operations professionals with a structured approach to navigate complex institutional challenges regarding traffic analysis. Application of the Traffic Analysis CMF will enable agencies to identify opportunities for improvement and develop a programmatic focus for traffic analysis to create analytical consistency and uniformity across and within Federal, State, regional, and local transportation agencies.

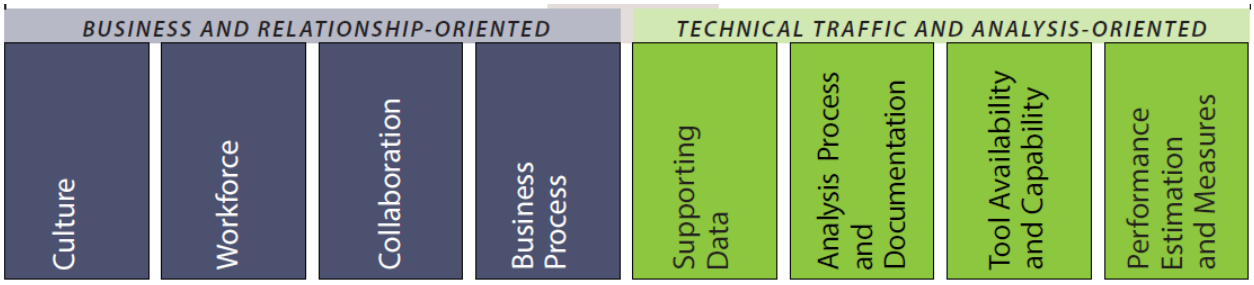
Traffic analysis is a complex but critical component of planning, designing, constructing, and operating the transportation system. Many different analysis tools can aid in these analyses, each of which has been designed to address a specific need or application(s). These tools can provide a high level of intelligence to execute informed transportation decisions about the likely effects, positive and negative, of alternative solutions.

An agency may want to use this CMF because capability maturity offers an approach to review barriers to adoption and success of traffic analysis. The framework enables a rigorous common understanding of institutional issues an agency may continually face. By understanding and using a CMF, agencies will be able to:

- Develop consensus around needed agency improvements
- Identify their immediate priorities for improvements
- Identify concrete actions to continuously improve capabilities to plan, design, and implement traffic analysis

2.1 DIMENSIONS OF THE FRAMEWORK

As illustrated in figure 1, this Traffic Analysis CMF evaluates eight dimensions of an agency's capabilities, considering the specific nature of traffic analysis.



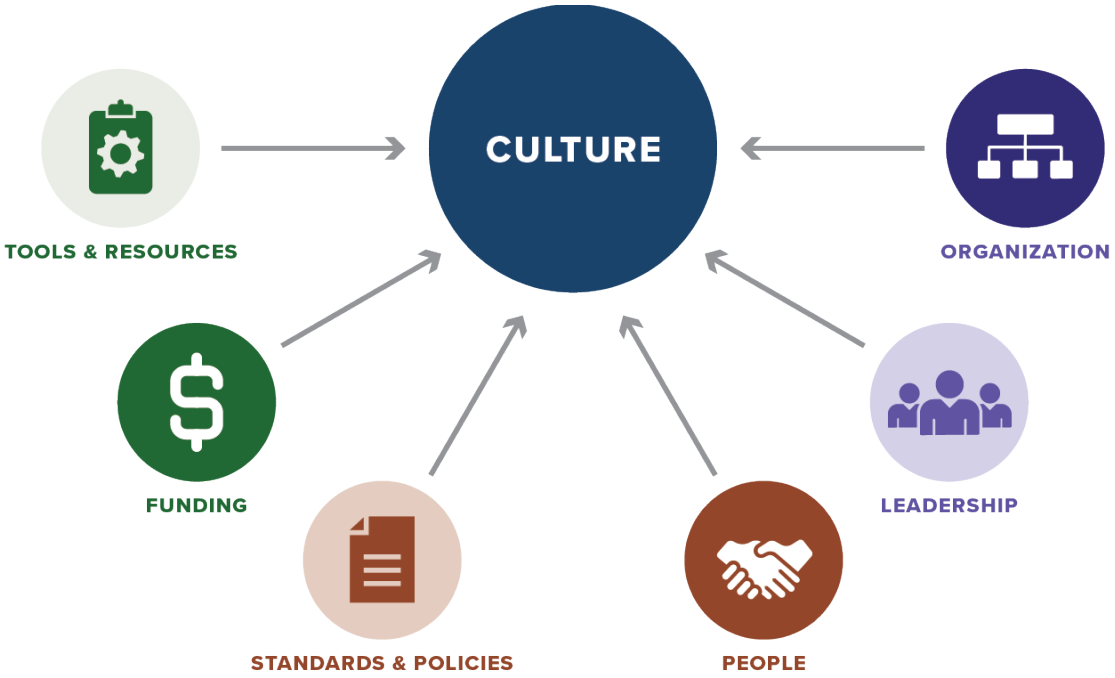
Source: FHWA.

Figure 1. Illustration. Traffic analysis capability maturity framework dimensions.

Culture

The culture dimension involves leadership, outreach, and technical understanding of analysis capabilities and needs at different levels within the agency. It also identifies if the agency philosophy allows for spending appropriate funding and time to collect robust data, use the

appropriate tools, develop the models, calibrate and validate the models, and review the models. Figure 2 illustrates the culture dimension of traffic analysis. Promoting the culture of traffic analysis within an organization involves an understanding of traffic analysis importance from the leadership, a supportive organization and workforce structure, readily accessible tools and resources, as well as funding and policy support, as illustrated in figure 2.



Source: FHWA.

Figure 2. Illustration. Elements of the culture dimension of traffic analysis.

Culture Subdimension 1: Understanding Role and Value

This subdimension addresses whether managers at different levels of the organization understand the role and value of traffic analysis and modeling. The subdimension supports an integrated understanding of the analysis objectives, targets, and success measures. This understanding helps managers to support and advance traffic analysis and modeling practices within the organization.

Culture Subdimension 2: Cost Acceptance

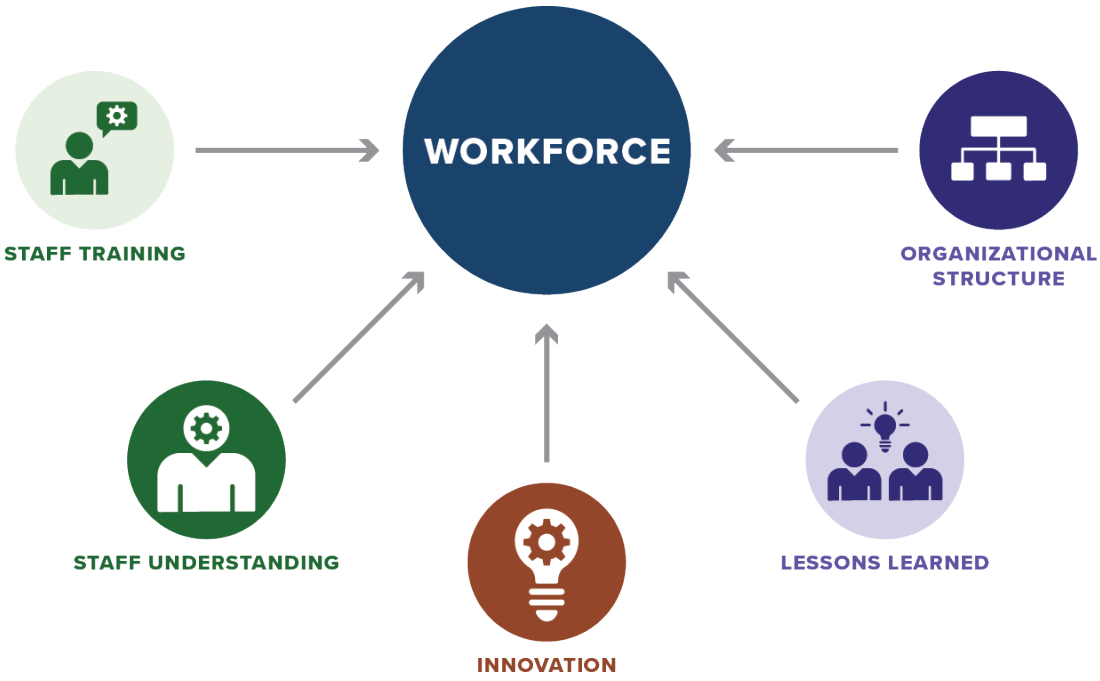
This subdimension addresses whether analysts can obtain adequate funds for performing analysis work to meet project requirements and, if extra funding is available, for advanced analysis tools and techniques to support evaluation of advanced strategies.

Culture Subdimension 3: Management and Operation Modeling

This subdimension addresses whether decisionmakers realize the importance of modeling TSMO strategies, ranging from basic signal control to advanced connected and automated vehicle (CAV) dynamic mobility applications (DMAs). Having decisionmakers realize the importance of off-line and real-time modeling combined with data analytics is key to get their buy-in and support to use modeling tools to evaluate TSMO strategies.

Workforce

The workforce dimension includes organizational structure, developing different levels of staff training such as overviews of concepts for decisionmakers, reviewer training, and various types and levels of AMS development training. It also includes identification of lessons learned, plus staff understanding and incorporation of the latest national and international developments. Figure 3 illustrates these elements of the workforce dimension.



Source: FHWA.

Figure 3. Illustration. Elements of the workforce dimension of traffic analysis.

Workforce Subdimension 1: Workforce Development

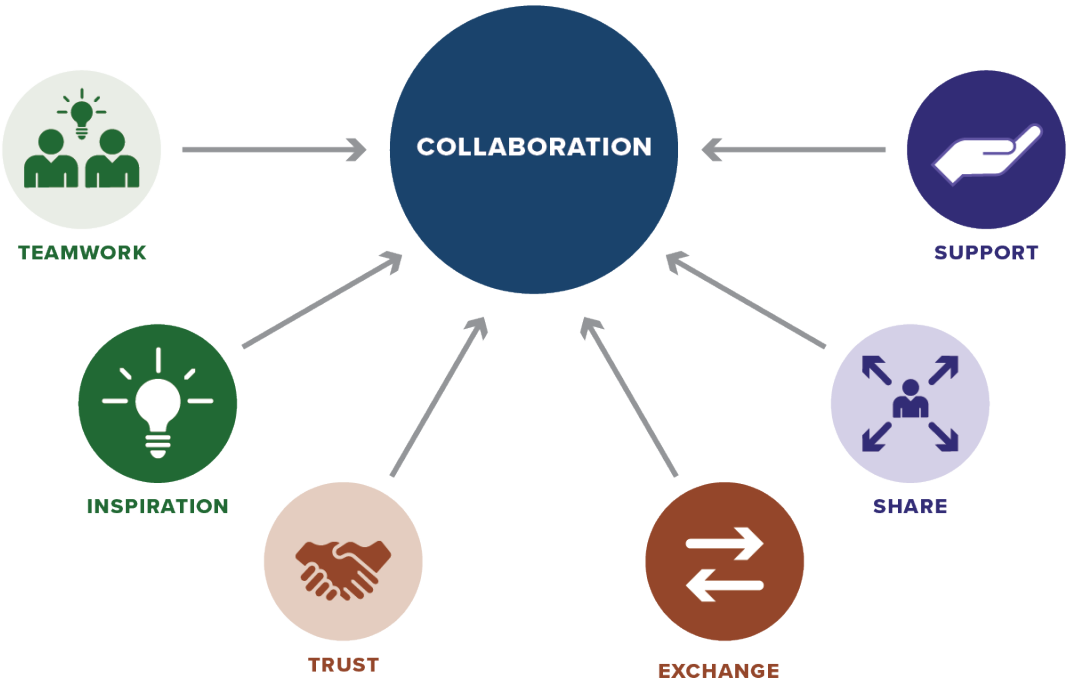
This subdimension addresses whether there is a robust workforce development and external support plan in place to guide the staff training, recruitment, and retention across different units of the organization. Having a robust workforce development plan helps to maintain and advance traffic analysis capabilities. The plan further ensures that these capabilities are not lost due to staff change.

Workforce Subdimension 2: Current Staffing Knowledge Skills, and Abilities (KSAs)

This subdimension assesses the capability of analysts and modeling staff to review and perform basic or advanced traffic analysis and modeling work. The subdimension also addresses training and knowledge-sharing mechanisms to assist staff in advancing their capabilities.

Collaboration

This dimension includes the relationships within and between agencies, local governments, MPOs, FHWA, and the consultant community responsible for conducting traffic analyses. This can include sharing and supporting each other on resources, data, and workforce development capabilities. Developing a collaborative relationship involves teamwork and building trust with each other, which can better inspire innovations to continuously enhance agencies' traffic analysis capabilities. Figure 4 illustrates these elements of the collaboration dimension.



Source: FHWA.

Figure 4. Illustration. Elements of the collaboration dimension of traffic analysis.

Collaboration Subdimension 1: Intra-agency

This subdimension addresses whether there is strong collaboration between different units within the same department and among different departments of an agency. Strong collaboration across the entire agency with roles and responsibilities clearly defined and integrated into the decisionmaking process is critical to maintain and advance traffic analysis practice of an agency.

Collaboration Subdimension 2: Inter-agency

This subdimension addresses whether there is a strong collaboration among different agencies. It considers documents such as a memorandum of understanding (MOU) to define the roles and responsibilities of different agencies. It further considers regulating and harmonizing the collaboration process to maximize the benefits of collaboration for all agencies.

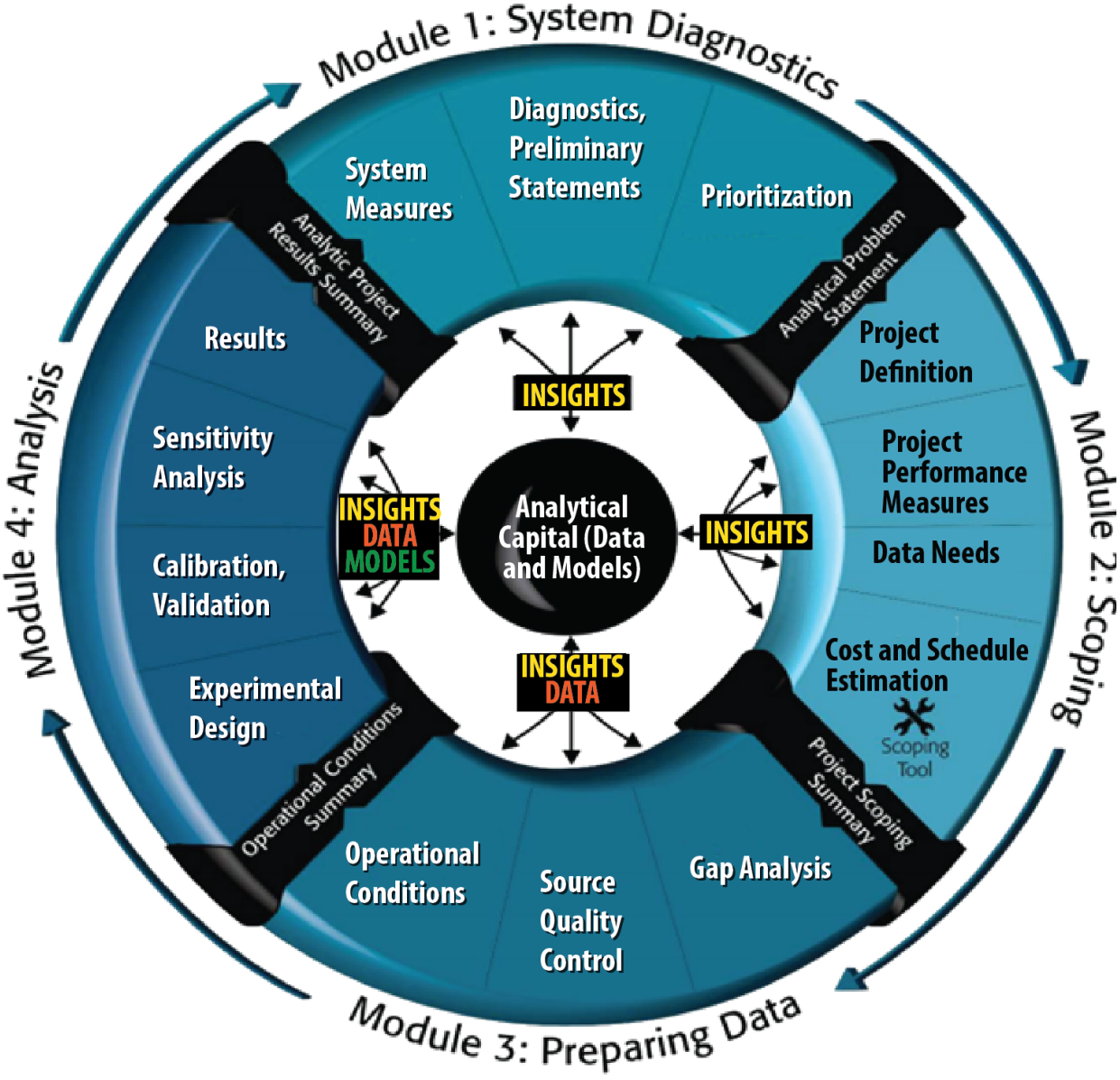
Business Process

The business process dimension involves development, use, and institutionalization of agency-level business processes for determining the role of different analysis types at different points in project planning and development. These analysis types range from high-level preliminary sketch planning evaluation and problem identification to detailed microscopic simulation analysis in support of agency decisionmaking. This dimension also includes identifying policies and procedures for the use of traffic analysis in individual projects. These policies and procedures include project objective setting and consideration, scoping, selection of analysis tool and approach, identification of resources, data requirement consideration, data analytics consideration, and model archiving and maintenance.

The business process dimension assesses how agencies formally incorporate analysis tools into business plans, action plans, agency planning manuals, engineering and design, environmental process, and operations. This assessment includes determining when and why the agency conducts traffic analysis. The assessment also includes identifying the needed type, resolution, and temporal and spatial extents of the analysis based on data analytics. The assessed policies and dimensions should clearly define the process of using the data for these purposes. FHWA's *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* (Wunderlich, Alexiadis, and Wang 2017) can help inform the approach, including starting with an analysis objective and examining the data to see if they support the objective, as well as the needed tools (e.g., HCM-level analysis versus simulation) and data. The business processes should include identifying the available and needed quality and quantity of data of the analysis prior to finalizing the analysis scope.

Business Process Subdimension 1: Scoping

The scoping subdimension addresses whether the agency bases its traffic analysis scoping on detailed instruction or policy. Scoping policy involves standard operating procedures (SOPs) required in all projects; instruction involves recommended procedures rather than required procedures. According to FHWA's S*coping and Conducting Data-Driven 21st Century Transportation System Analyses* (Wunderlich, Alexiadis, and Wang 2017), project scoping includes defining project details, identifying project-specific performance measures, refining mitigation strategies and data needs, selecting tools, and estimating costs and schedules. Figure 5 shows the scoping process outlined in FHWA's scoping guide.



Source: Wunderlich, Alexiadis, and Wang (2017).

Figure 5. Diagram. Scoping process outlined in *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses*.

Project scoping based on standard procedures for performance enables more consistent and effective setting of performance measurements, analysis methods, data needs, tool selection, and cost setting. The agency can assign a unit to lead the adoption and development effort, potentially with the help of a consultant. The agency can set policies by coordinating with stakeholders within the agency, which may include planning, design, and operations departments, as well as partner public agencies and consultants that are impacted by this effort.

Business Process Subdimension 2: Administration

Administration refers to the degree to which agencies support the use of traffic analysis with administrative staff, cost estimation methods, documentation, and templates. At the highest capability levels, the agency maintains procedures and templates that are customized for specific types of traffic analysis. The project administration and procurement can include identifying:

- The overall process of how analysts will conduct the project and deliver the product
- Procedures to evaluate and select among potential analysts based on identified criteria, such as qualifications, cost, project management, and subcontractors
- Estimating and obtaining the required funding for the analysis

Business Process Subdimension 3: Institutionalization

Institutionalizing traffic analysis refers to the degree to which agencies formalize the use of traffic analysis to support agency functions and processes. Some agencies with strong traffic AMS practices limit the application of AMS to specific functional areas and do not pursue AMS in some cases where AMS could help. Others may incorrectly use the results to support decisions associated with their functions and processes. These functions and processes include long-range planning, corridor studies, access management, impact studies, TSMO, CAV, and mobility as a service (MaaS). Agencies can formalize the reporting of results and the use of results to support decisionmaking for specific types of analysis. Agencies can include such information in the strategic plans, business plans, action plans, and manuals associated with these functions. This institutionalization will allow the mainstreaming of traffic analysis and the use of traffic analysis in the decisionmaking processes to benefit functions of the agency. Planning and design units will coordinate this effort with the unit responsible for advancing analysis practice of the agency and potentially partner agencies.

Business Process Subdimension 4: Archiving and Maintenance

This subdimension refers to archiving and maintaining data, analysis files, and documents for future use. At the highest level of capability maturity, the agency will have a documented process for archiving, sharing, updating, and maintaining archived files. The agency will require future analysis teams to share updates to the original models in subsequent projects for incorporation into the archive, subject to an approval process. Archiving and maintaining data, analysis files, and documents will allow follow-up analyses to confirm the original analysis results and will allow further analysis that had not occurred in the original project. In addition, archiving and maintenance will reduce the cost of AMS efforts that include all or part of the original model area. A unit responsible for advancing analysis practice in the agency, possibly with support from partner agencies, will lead this effort.

Supporting Data

This dimension involves how the agency identifies data needs and availability used in developing, calibrating, and validating the analysis. FHWA's S*coping and Conducting Data-Driven 21st Century Transportation System Analyses* (Wunderlich, Alexiadis, and Wang 2017)

provides information in this area. This dimension also includes how the agency identifies data needs for a project and addresses the data gaps and data quality. This dimension addresses the supporting tools for preparing different resolutions of data appropriate to supplement the analysis. This dimension also addresses data ingestion, cleaning, processing, storage, and governance to support traffic analysis. The unit responsible for advancing analysis practice in the agency will lead this effort, in coordination with private sector data providers and public sector agencies that collect and maintain the data.

Supporting Data Subdimension 1: Data Requirement Setting

This subdimension emphasizes the need for data requirements to ensure analysts obtain all needed data items for model development and calibration considering simulation data completeness, quality, and resolution (in time and space). The subdimension also involves the use of various filtering and correction techniques to ensure the desired quality of the data. *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* (Wunderlich, Alexiadis, and Wang 2017) mentions that it is possible to have significant temporal and spatial inconsistencies in the data, even when analysts have already checked the data before archiving. Thus, the analyst should carefully check inconsistencies in the data. Data requirements, availability, quality, and consistency and filling data gaps are key considerations for the project. Analysts should develop a detailed data plan that includes checking data quality as a key component.

Missing, inconsistent, inaccurate, and erroneous data can lead to wrong inputs to the models and affect the quality of the calibration. The resolution of the data in time and space are also important. As an example, the analysis may require the measurement of travel times for a segment between two intersections. The analysis team may have planned to use travel time data from a third-party vendor. However, examination of the data may indicate that the spatial resolution of travel time data from this vendor is too coarse. In this case, the analyst will have to identify other sources of data that meet the requirements.

Supporting Data Subdimension 2: Data Analytics

This subdimension refers to the capability to perform data analytics and visualization to support traffic analysis. Data analytics and visualization can support the development and calibration of AMS tools. For example, analysts can use clustering analysis to select the scenarios and representative day for modeling. Visualization of a heat map of various performance measures, and the variation of the heat map throughout the year, can provide an important input to calibration. Analysts can also use data analytics in combination with modelling in an integrated analysis framework to support decisions. The analyst can initially use data visualization and analysis tools developed for other purposes, such as TSMO. Advancement in this capability ultimately involves integrating tools specifically developed for AMS into the data and modeling environment. The parties responsible for advancing this subdimension are the unit responsible for advancing analysis practice in the agency, and the agencies responsible for developing and maintaining tools used for other purposes.

Supporting Data Subdimension 3: Multiple Data Sources

This subdimension references the use of data from multiple sources, including existing and emerging technologies, to satisfy AMS data needs. Various emerging data sources in recent years can support AMS. The agency considers the strengths and limitations of these data sources when identifying the data for AMS. These sources include point detectors installed by TSMO programs, vehicle re-identification technologies (e.g., Wi-Fi readers), private sector travel time data, private sector origin-destination (O-D) data, high-resolution controller data, CAV data, vehicle trajectories, incident data, crash data, construction data, and weather data. The collected vehicle trajectories can be mesoscopic, allowing the identification of routes used by each vehicle, which is important to calibrate assignment models. Analysts can obtain this data from sources such as connected vehicles, automatic vehicle re-identification using technologies such as Bluetooth® readers, and third-party vendors. The trajectories can also be at the microscopic level to enhance calibration of microscopic simulation model attributes, such as car following, lane changing, and gap acceptance. Analysts can obtain these trajectories based on connected vehicle data and advanced image processing sensors. These various sources allow agencies to choose data that best meet project requirements and improve the quality of AMS.

Supporting Data Subdimension 4: Data Exchange

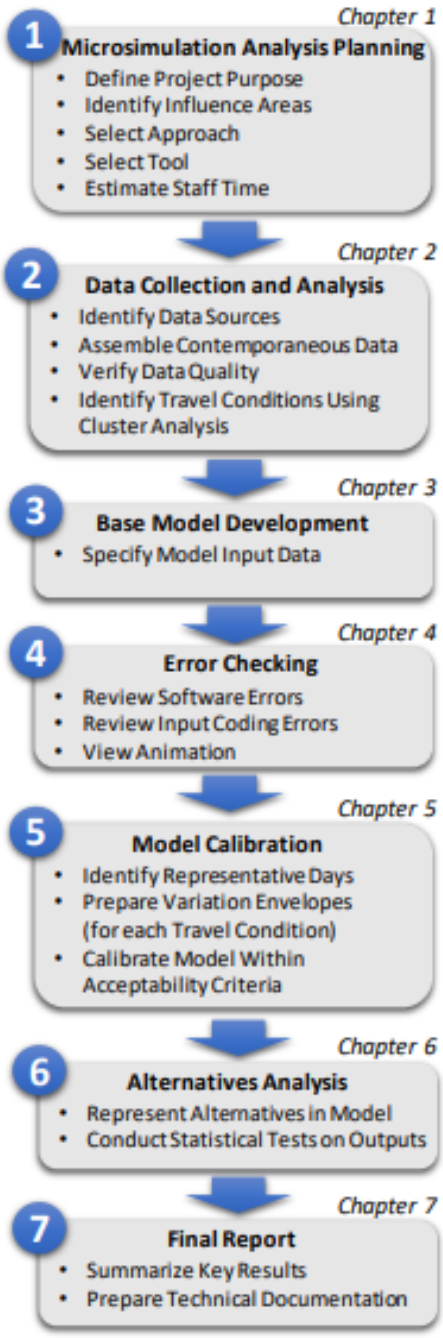
This subdimension focuses on archiving the data, potentially considering analysis needs, and providing a data exchange mechanism that allows easy access by the user. Analysts archive collected data from different sources for easy access.

Supporting Data Subdimension 5: Data Management and Governance

This subdimension refers to advanced data management techniques, including data governance. Data governance involves defining and aligning rules, providing protection and services to data stakeholders, and reacting to and resolving issues arising from noncompliance with rules. Data management governance processes ensure information availability, usability, consistency, integrity, and security. Data governance also ensures accountability for the adverse effects of poor data quality.

Analysis Process and Documentation

Traffic analysis can be a substantial effort. Once completed, the assembled and developed data sets can support a large number of future analyses, applications, and projects. This dimension addresses how agencies implement the various steps involved in the analysis process. Although the business process dimension references some of the steps as part of scoping and standard operations instruction at a strategic and tactical level, the analysis process and documentation dimension address the analysis steps at the application level with focus on their applications in practice. An important aspect of this dimension is clear documentation of all analysis activities and results in detail. This allows analysts and reviewers to clearly understand the details of applying each of the steps, and to determine if analysts conducted the project according to agency requirements. Existing State instruction has similar categorizations of the steps as those in figure 6. This dimension addresses the agency applications of all these steps.



Source: Wunderlich, Vasudevan, and Wang (2019).

Figure 6. Flowchart. The seven steps in the *Traffic Analysis Toolbox Volume III* methodology.

Analysis Process and Documentation Subdimension 1: Analysis Approach

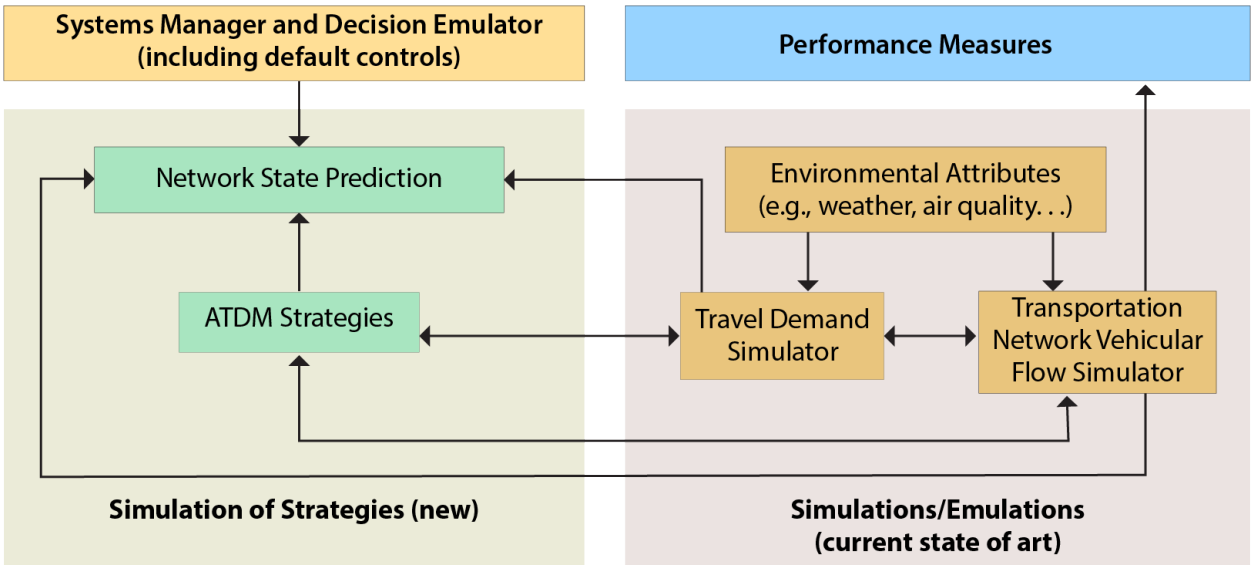
This subdimension addresses the agency capabilities in conducting different types of traffic analysis to satisfy project analysis requirements. At the basic level, most agencies are able to conduct analyses typically utilizing deterministic tools, or in some cases simulation of short segments or single intersections. Examples of improved capabilities may include analysis of

travel time reliability, queue spillback, platoon progression, multiple time periods, larger networks, DTA, multiple resolutions, multiple travel modes, and multiple operating conditions. In addition, agencies may ultimately integrate data science and business intelligence into their traffic analyses. Such capabilities will enable the agency to select the analysis approach that best satisfies the project requirements.

Analysis Process and Documentation Subdimension 2: Advanced and Emerging Strategies

This subdimension addresses the agency's ability to analyze and model advanced and emerging strategies, including ramp metering, adaptive signals, dynamic shoulder use, dynamic lane grouping, managed lanes, and integrated corridor management. It also addresses the agency's ability to analyze and model emerging technologies such as CAVs, cooperative driving, and MaaS,

FHWA conducted a series of projects to identify the best AMS approaches to assess ATDM strategies and DMAs for connected vehicles. As part of this effort, the FHWA funded testbeds in six locations (FHWA 2013a; FHWA 2013b; Vasudevan and Wunderlich 2013). This series of projects investigated a suite of modeling tools and methods that allows evaluation of the potential benefits of implementing ATDM and DMA strategies for planning, design, and operations purposes. The AMS effort emphasized the importance of MRM in analyzing TSMO strategies. The AMS testbed effort emphasized that it is essential to capture the dynamic interactions between supply and demand and multi-scenario analysis. As an example, figure 7 illustrates the framework used in the U.S. Route 75 corridor testbed in Dallas, Texas (Yelchuru et al., 2017).



Source: Yelchuru et al. (2017).

Figure 7. Flowchart. U.S. Route 75 integrated corridor management project analysis framework.

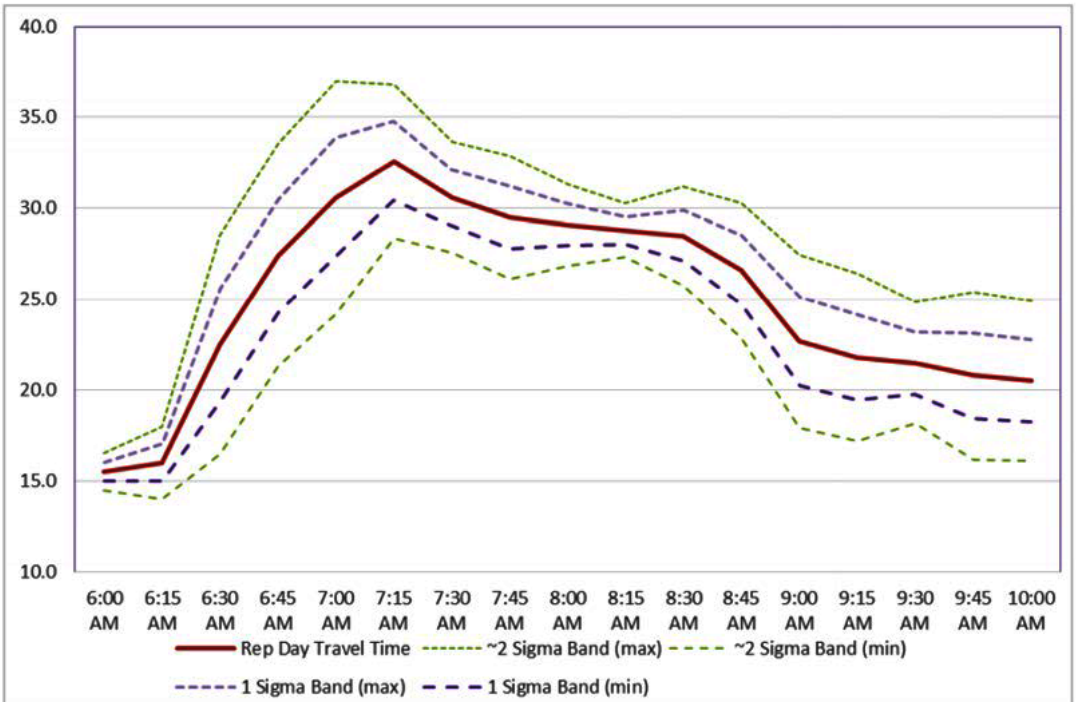
FHWA developed a comprehensive CAV AMS framework (Mahmassani et al., 2018) to guide CAV AMS model development effort. However, the information provided in that document can

be helpful in modeling CAV. The framework includes four main dimensions of CAV modeling: supply changes, demand changes, performance changes, and network integration. Depending on the analysis objectives and scopes, analysts may include all or a subset of the four dimensions in the project modeling framework.

Analysis Process and Documentation Subdimension 3: Verification, Calibration, and Validation

Verification, calibration, and validation (VC&V) are key to advanced and/or comprehensive traffic analysis projects. At the time of this writing, no standard industry definition is available for these. According to chapter 8 of the *Transportation Systems Simulation Manual* (TSSM), verification "pertains to checking the logic, the software, and the input data" and calibration "involves checking the parameter values based on the output data for data sets deemed useful for calibration purposes" (List et al., Forthcoming). Validation "pertains to checking the output predictions based on the output data given the input data for the validation data sets" (List et al., Forthcoming). The European Multitude project performed a worldwide survey on VC&V practices (University of Naples Federico II 2015) and found that roughly half of traffic modelers typically do not attempt to perform calibration within their traffic analyses. This is concerning, considering that a detailed traffic model is unlikely to realistically represent the real world without VC&V. Some analysis instruction documents that consistently require calibration do not similarly require validation, which can also compromise model integrity.

Traffic Analysis Toolbox Volume III (Wunderlich, Vasudevan, and Wang 2019) emphasizes the importance of calibration. Volume III replaced the methodology from the 2004 version with a new methodology that uses dynamic calibration targets based on data collected over a long period of time (e.g., a year). Figure 8 shows one step of the methodology to derive a variation envelope around the representative day as presented in *Traffic Analysis Toolbox Volume III*. This step establishes the variation in conditions the facility experiences and a process to calibrate to those observed conditions. The process is statistically founded on real data for the locations being analyzed.



Source: Wunderlich, Vasudevan, and Wang (2019).
min = minimum. max = maximum. Rep = representative.

Figure 8. Graph. Variation envelope concept.

Analysis Process and Documentation Subdimension 4: Analysis Reporting and Documentation

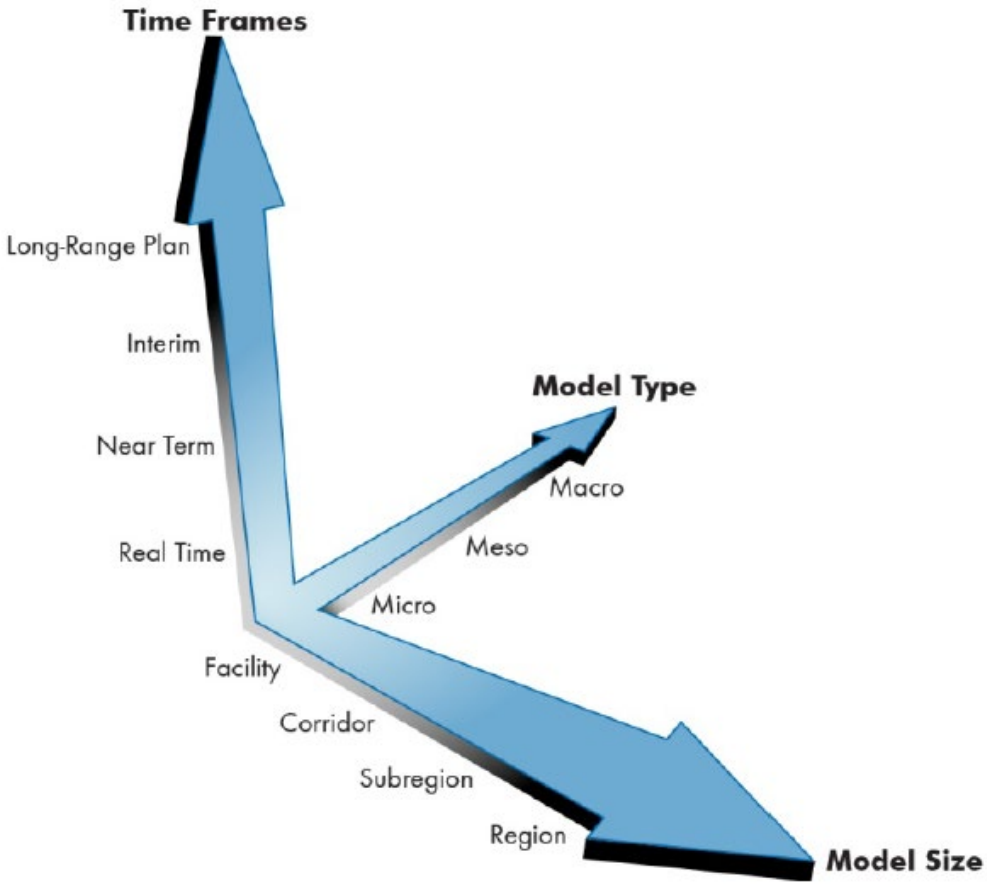
This subdimension addresses the level of detail and consistency of the reporting and documentation of the analysis activities and results. The improved capabilities can include requirements for the production of analysis project documentation. The produced documents provide information to allow reviewers to understand the analysis processes, results, and conclusions based on results in the report.

Tool Availability and Capability

This dimension refers to data- and model-based tools selected by the agencies to perform different levels and resolutions of the analysis, including selecting the right data and modeling tools for the analysis. *Traffic Analysis Toolbox Volume II* (Jeannotte et al., 2004) describes key considerations within the traffic analysis tool selection process. This dimension addresses an agency's application of combinations of tools with various resolutions to meet project needs. This dimension also addresses MRM tools, plus supplementary or add-on tools that support the use of the main modeling tools. The modeling tools can include basic deterministic/analytical tool-based analysis and simulation tool capabilities, including multiresolution, multimodal, multi-scenario, emerging technologies (e.g., CAV), and trajectory-based analysis, as well as the provision of application programming interfaces (API). The assessment in this dimension addresses the agency's capability in obtaining, developing, and using the tools, as well as in reviewing the developed models.

Tool Availability and Capability Subdimension 1: Tool Selection

This subdimension addresses the agency's capability to select traffic analysis tools for various projects considering funding, schedule, and resource constraints. Given the rapidly changing traffic control strategies, management technologies, data sources, tool capabilities, and computer capabilities, the importance of careful tool selection will probably continue to grow. *Traffic Analysis Toolbox Volume II* (Jeannotte et al. 2004) provides high-level tool selection criteria that includes the analysis context, study area, facility type, travel mode, management strategy, traveler response, performance measures, and cost-effectiveness. Figure 9 shows that analysts typically use microscopic, mesoscopic, and macroscopic models to analyze small, medium, and large spatiotemporal scopes, respectively (Sloboden et al., 2012).



Source: Sloboden et al. (2012).

Figure 9. Illustration. Model selection based on spatiotemporal considerations.

MRM tool packages and suites offer various advantages and disadvantages. For example, some MRM tools focus more on macroscopic and mesoscopic analysis. Some MRM tools focus on microsimulation while applying the other analysis resolutions to improve the microsimulation robustness. Some MRM tools are more efficient at incorporating activity-based models. Some tools offer hybrid simulation to model key parts of the region in microsimulation, while simultaneously modeling less important areas of the network in mesoscopic simulation. Some microsimulation tools attempt to sidestep MRM by offering capabilities such as DTA.

In a pair of transportation planning and traffic management reports, Hadi et al. (2012, 2016) recommended development and use of tool assessment criteria as part of a supporting environment for MRM. The criteria enable comparing various modeling tools to ensure they meet the needs of a project. The criteria for tool assessment covers general hardware and software, shortest path and path choice modeling, traffic flow modeling, network geometry modeling, network demand modeling, transit modeling, and calibration/validation and convergence assurance support. Hadi et al. (2012, 2016) developed additional criteria for specific applications such as managed lane, work zone, and advanced traffic management strategy modeling.

Tool Availability and Capability Subdimension 2: Tool Availability

This subdimension addresses the tools an agency has resources to procure and is willing to apply. Traffic analysis tools are a significant investment in terms of license fees, staff training, data requirements, and VC&V requirements. If an agency's local jurisdiction exhibits minimal traffic congestion confined to short (e.g., 15–30 minutes) peak periods, the agency may not have a significant need or justification for advanced simulation models. Some agencies faced with extensive traffic congestion may seek the capability to apply a wide range of analysis types and tools. However, other agencies prefer the simplicity that comes with specific vendors and analysis types.

Performance Estimation and Measures

This dimension addresses post-processing, visualization, presentation, and reporting of the output data generated by traffic analysis. This can include estimating various measures related to meeting agency objectives, such as mobility, reliability, environmental impacts, and safety measures. This dimension also includes monitoring post-project construction performance to determine the quality of the analysis results. This dimension also assesses how well the agency estimates and uses the estimated performance measures to support decisions. This includes how the agency selects and defines the performance measures (also known as measures of effectiveness (MoE)) based on agency and project objectives and desired outcomes, how the measures are estimated based on analysis outputs, and how the measures are used to support the decisionmaking process. Another aspect is monitoring real-world performance measures of an existing facility to trigger the need for analysis based on established criteria.

Performance Estimation and Measures Subdimension 1: Performance Measure Selection

The purpose of assessing traffic performance MoE is to determine the system performance under specific or varying traffic conditions, plus the impacts of improvements and other types of intervention. The selection of performance metrics will reflect agency objectives, project objectives, and desired outcomes. The following parameters can help to define and describe the selected measures:

- Name and definition
- Analysis period (e.g., every 15 minutes, hourly, peak period, daily)
- Geographic extent and resolution

- Required data and data sources
- Calculation method and formula
- Unit of measurement
- Benchmarking values and targets
- Method of presentation for the end user
- Connection to the goals and objectives

The following dimensions can help to report the selected measures:

- Time of day
- Day of week
- Season
- Road segment and/or intersection
- Weather
- Incident scenario
- Work zone scenario
- Special events
- Demand scenario
- User type
- Vehicle type
- Vehicle technology type

In addition to the primary mobility metrics from the AMS tools, agencies are interested in efficient methods to estimate reliability, emissions, and safety measures. Due to the limited outputs from existing tools related to these measures, the calculation of these measures requires post-processing of the outputs. This section describes the processes used for this purpose.

Performance Estimation and Measures Subdimension 2: Performance Measure Estimation

This subdimension refers to how the agency obtains or calculates the performance measures based on model outputs. Analysts obtain and assess performance measures by using field data and traffic modeling. There are significant differences in the methods used to estimate the measures in analytical deterministic procedures and tools like those associated with the HCM (TRB 2016) versus those applied by simulation tools. There are also significant differences on how the simulation tools themselves calculate the measures relative to each other. The methods used in estimating the measures based on modeling may also differ from the methods used in calculating the measures based on the field data.

Performance Estimation and Measures Subdimension 3: Performance Measure Use

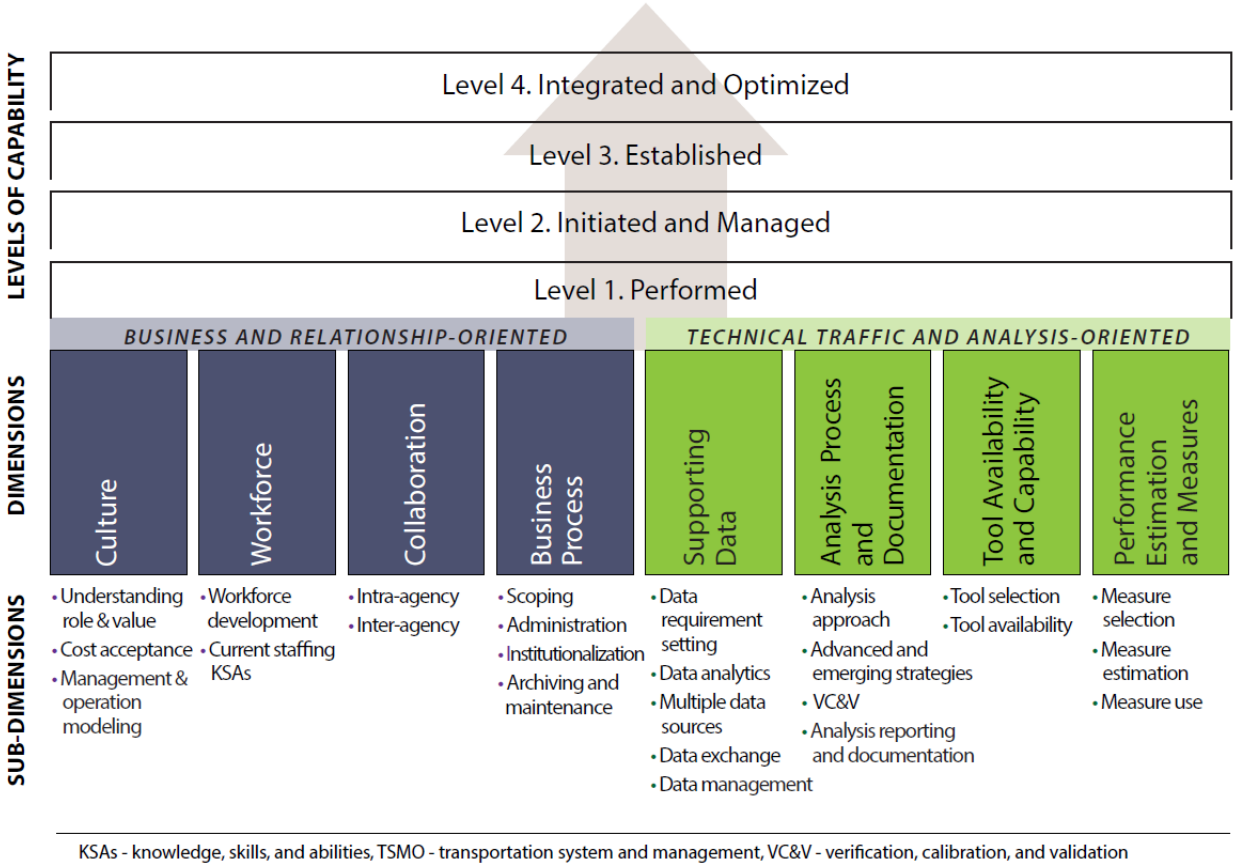
Decisionmakers at different levels use the assessment of performance measures to make their decisions. Upper-level decisions reflect a wider scope and a coarser granularity. By contrast, operations staff and highway designers apply high-resolution and more detailed metrics. This subdimension focuses on how the agency uses analysis performance metrics in its decisionmaking processes. This includes using statistical analysis, visualization techniques, preliminary analysis measures to determine simulation needs, sensitivity analysis to determine the potential range of results, and an integrated business intelligence process for decision support.

2.2 CAPABILITY MATURITY LEVELS

As in the original TSMO CMM (Gregory 2012), the proposed framework uses four levels of capability for each dimension of the Traffic Analysis CMF, which are defined as follows:

- **Level 1—Performed:** Activities and relationships largely ad-hoc; informal and champion driven; project-driven data and analysis activities; ad-hoc analysis of performance or strategies
- **Level 2—Initiated and Managed:** Commitment to improve AMS activities; key analysis steps and associated requirements identified and understood; basic instruction and training developed; limited identification and implementation of business processes; limited accountability for processes; uneven alignment with external partners
- **Level 3—Established:** Standardized operating procedures and policies for analysis, tool utilization, quality assurance, training, retention, and use of outputs for decisions; model archiving and maintenance; internal accountability assured; partnerships aligned
- **Level 4—Integrated and Optimized:** Activity institutionalized and continuously improved; sustainable analysis program priority; continuous improvement based on feedback loop and lessons learned; integrated analysis process and decision support at different levels, from operational to strategic; optimized contracting and procurement

Figure 10 shows how an agency can exhibit different levels of capability within the fundamental dimensions of traffic analysis. The figure also illustrates the eight dimensions comprised of 25 subdimensions.



Source: FHWA.
TSMO = transportation systems management and operations; VC&V = verification, calibration, and validation.

Figure 10. Illustration. Overall traffic analysis capability maturity framework.

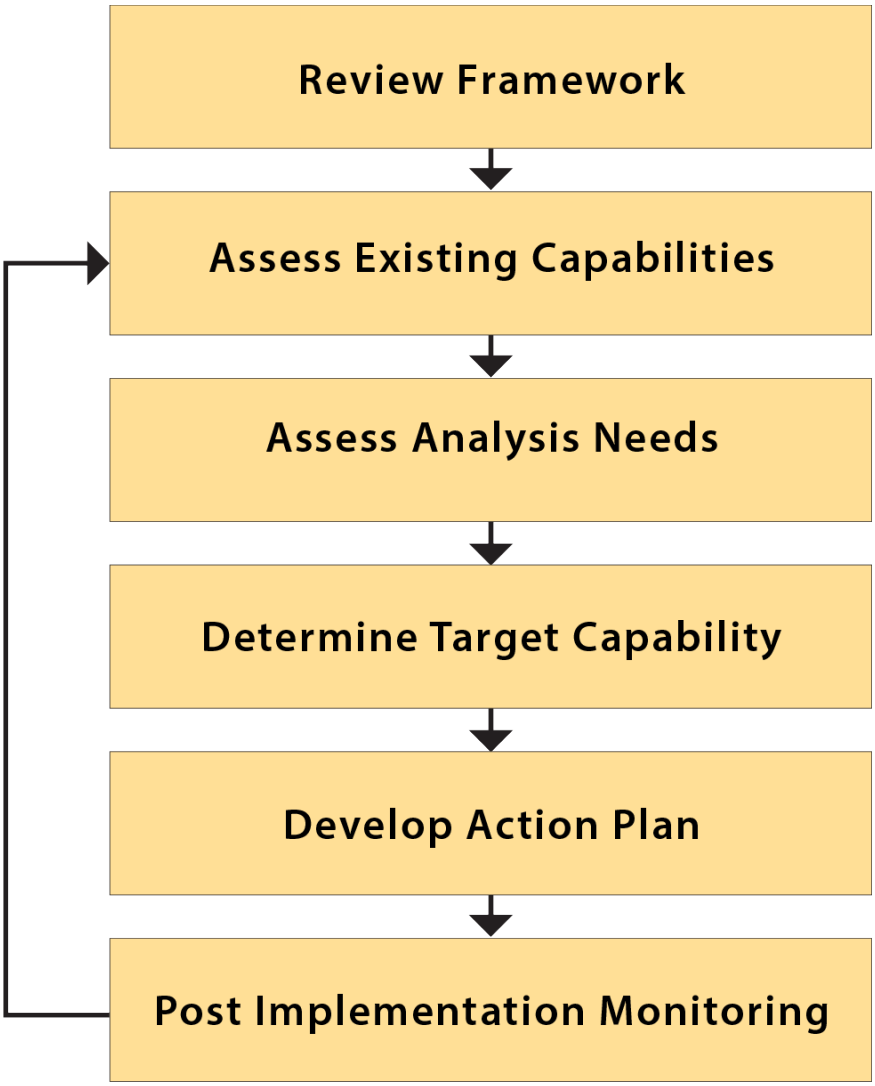
2.3 OVERVIEW OF STEPS TO USE THE FRAMEWORK

The framework presented in this document provides a systematic approach for transportation agencies to assess their current capabilities and identify actions that may be taken to improve these capabilities. This section describes how agencies can use the Traffic Analysis CMF to self-assess their strengths and weaknesses and to identify recommended actions to improve their capabilities in different dimensions of traffic analysis.

Before starting the assessment process, the transportation agency can identify the scope of the self-assessment including the purpose, goals, and stakeholders to participate in the self-assessment process. Before initiating the assessment, the lead agency and partners may want to identify the individuals best positioned to address the various steps of the CMF. Then, the agency and stakeholders can identify the desired level for each of the traffic analysis capability subdimensions, and the specific desired capabilities for each subdimension level. This identification can reflect agency needs and local conditions and should occur prior to the assessment process.

Figure 11 shows the steps of the Traffic Analysis CMF. Agencies should use a collaborative process when applying the CMF. This could involve a stakeholder workshop. The stakeholders

can first determine their capability level using the approaches described in chapter 3 of this document. The stakeholders could then identify, filter, and compile a set of actions appropriate to the region or agency, using the information in chapter 4 of this document. Typically, a local lead agency or department will organize the stakeholder workshop. Follow-up meetings can then identify how to implement and review the implementations of the actions.



Source: FHWA.

Figure 11. Flowchart. Steps for using the traffic analysis capability maturity framework.

The developed Traffic Analysis CMF will allow the self-assessment of capabilities in a collaborative process involving multiple stakeholders. Depending on the scope of the assessment (e.g., internal agency capabilities versus regional capabilities), stakeholders should include a mix of perspectives (e.g., decisionmakers, traffic analysts, demand forecasting modelers, project managers and designers, MPO staff, and TSMO managers).

The agency can interpret the results of the self-assessment and use the results in developing an action plan to improve its analysis capabilities. The action plan will identify the approaches and

resources that agencies should use to advance their analysis capabilities. The agency should update this action plan as they implement various actions and assess their effectiveness, while considering lessons learned and newly identified needs for additional capabilities.

CHAPTER 3. ASSESSMENT OF CURRENT CAPABILITY

This chapter provides an assessment of capabilities via easy-to-use lookup tables and a short set of multiple-choice questions. The answers to the multiple-choice questions are specific to the self-assessing agency only. First, the agency can use a matrix that identifies the expected capabilities under each level and each dimension. Second, the chapter provides a series of multiple-choice questions that can be used in combination with (or in lieu of) the tables for capability assessment, depending on the CMF user's preferences. In some cases, the multiple-choice questions contain more verbose information than the tables. Some users may prefer the use of the question-and-answer format, particularly in a stakeholder workshop setting. The agencies' answers to the questions can help to further identify the capability maturity of the agency.

The chapter includes one multiple-choice question for each subdimension of the eight dimensions (i.e., 25 total questions for the 25 subdimensions). Each answer is averaged on a scale of 1–4 to get an overall average for a given dimension: 1 = performed, 2 = initiated and managed, 3 = established, 4 = integrated and optimized. If the agency answers a question with "not applicable," that question is removed from the calculations. Individuals who have detailed experience and knowledge of the organization's capabilities in traffic analysis can provide answers to the questions. An effective setting for this is a stakeholder workshop with a facilitator to assist participants in providing answers.

The criteria for assessing the level of maturity is general. Agencies can tailor the criteria to different users (e.g., single department, agency, or multi-agency partnerships) or refine the criteria to address specific analysis applications, such as multi-resolution or emerging technology analysis. An agency may discover that its maturity level lies between levels, as the agency may satisfy some but not all capabilities required at the next level.

3.1 CULTURE

This section provides a matrix of suggested criteria for each capability level (table 1), followed by multiple-choice questions to confirm the capability within each subdimension, for the culture dimension.

Table 1. Criteria for maturity levels within the culture dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Understanding role and value	Little understanding from decisionmakers on role and value of analysis. Activities are champion driven.	Lower-level managers understand importance of different levels of analysis, including enhanced analysis capabilities.	Upper management understands the need to support and invest in modeling practices and advancing these capabilities to reach higher levels of maturity.	Managers at different levels have an integrated understanding of objectives, measures of success, and targets for modeling use.
Cost acceptance	Analysts find significant obstacles to get needed funds for detailed traffic analysis when needed.	Analysts can get funds for detailed traffic analysis when needed, only in some cases and up to a certain limit.	Analysts can get needed funds for detailed traffic analysis whenever such analysis is required to meet project objectives.	Projects can get the extra funds required for advanced traffic analysis and analysis of advanced and emerging strategies. Examples of advanced techniques include multi-scenario modeling, multiresolution modeling (MRM), dynamic traffic assignment (DTA), and incorporation of high-resolution data sources into the calibration process.
Management and operation modeling	Decisionmakers do not think analysis of operations strategies is needed.	Decisionmakers recognize importance of modeling some operations strategies, such as ramp metering and managed lanes.	Decisionmakers realize importance of modeling advanced and emerging operations strategies, such as active traffic management, incident management, and connected and automated vehicle (CAV) dynamic mobility applications (DMAs).	Decisionmakers recognize the importance of off-line and real-time modeling, combined with data analytics in an integrated framework, to support the modeling of advanced and emerging operations strategies.

Q1: How do you describe the agency managers' understanding of the role and value of traffic analysis?

a. There is little understanding of the role and value of analysis by decisionmakers and upper management. The activities are champion-driven.
b. Lower-level managers understand the importance of different levels of analysis, including enhanced traffic analysis capabilities.
c. In addition to the capability in b, upper management understands the need to support and invest in analysis capabilities, and advancing these capabilities to reach higher levels of maturity.
d. Managers at different levels have an integrated understanding of objectives, measures of success, and targets for modeling use.

Q2: How do you describe the culture in your agency in regard to approving the needed funding required for different levels of traffic analysis?

a. Projects have significant obstacles to get funds for the use of detailed traffic analysis when needed.
b. Projects can get funds for detailed traffic analysis when needed, only in some cases and up to a certain limit.
c. Projects can get funds for detailed traffic analysis whenever such analysis is essential to meet the project objectives.
d. Projects can get the extra funds needed for advanced traffic analysis and analysis of advanced and emerging strategies. Examples of advanced techniques include multi-scenario modeling, MRM, DTA, and incorporation of high-resolution data sources into the calibration process.

Q3: How do you describe the culture in your agency with regard to the modeling of advanced and emerging strategies and technologies?

a. Decisionmakers do not think that modeling operations strategies is needed.
b. Decisionmakers recognize the importance of modeling some operations strategies, such as ramp metering and managed lanes.
c. Decisionmakers realize the importance of modeling advanced and emerging operations strategies, such as active traffic management, incident management, and CAV DMAs.
d. Decisionmakers recognize the importance of off-line and real-time modeling combined with data analytics in an integrated framework, to support the modeling of advanced and emerging operations strategies.

3.2 WORKFORCE

This section provides a matrix of suggested criteria for each capability level (table 2), followed by multiple-choice questions to confirm the capability within each subdimension, for the workforce dimension.

Table 2. Criteria for maturity levels within the workforce dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Workforce development	No formal effort for staff development, training, recruitment, and retention.	Provide limited training. One or more units assigned to grow practices in the organization. Organize workshops and seminars to build the staff capabilities.	Evolving and improving program in development, training, recruitment, and retention. Training on basic and advanced topics on development and review of models.	Robust staff development, training, recruitment, and retention.
Current staffing knowledge, skills, and abilities (KSAs)	Skills to develop models limited to consultants. Limited internal skills to approve and use model results for agency decisionmaking.	Some internal review capabilities (mainly based on project documentation), but still considerable reliance on third-party reviews, particularly in reviewing model input and output files. Limited internal training in analysis and simulation, and in some cases on the associated tools.	Good internal experience in simulation and analysis tools. Existing staff can adequately review software inputs and outputs. Internal training on basic and advanced topics, on development and review of models.	Staff follow, participate in, understand, and incorporate latest national and international developments, and incorporate lessons learned in their traffic analyses.

Q4: How do you ensure effective training, retention, and recruitment of staff to conduct and review the traffic analysis?

a. There is no formal effort for staff development, training, recruitment, and retention.

b. We provide limited training. We assigned one or more units to grow practices in the organization. The units organize workshops and seminars to build staff capabilities.

c. We have an evolving and improving program in staff development, training, recruitment, and retention.

d. We have a robust program in staff development, training, recruitment, and retention. For example, we maintain multiple sets of educational material that focus on specific types and functions of traffic analysis. For staff recruitment, we maintain job announcements, interview questions, and lists of required and desired capabilities that focus on specific types of traffic analysis.

Q5: How do you rate the current proficiency (i.e., KSAs) of your team in traffic analysis, and how are you working on enhancing the proficiency?

a. Our consultants generally provide the skills to conduct analysis, particularly simulation. There are limited internal skills to approve and use model results for agency decisionmaking.

b. There are some internal review capabilities, mainly based on the provided project documentation. There is still considerable reliance on third-party reviews, particularly in reviewing model input and output files. We provide limited training in analysis and simulation, and in some cases on the associated tools.

c. Our staff has good experience with the simulation and analysis tools and can review model inputs and outputs. We provide training on basic and advanced topics, on development and review of models.

d. Our staff follows, participates in, understands, and incorporates the latest national and international developments, and incorporates lessons learned in their traffic analyses.

3.3 COLLABORATION

This section provides a matrix of suggested criteria for each capability level (table 3), followed by multiple-choice questions to confirm the capability within each subdimension, for the collaboration dimension.

Table 3. Criteria for maturity levels within the collaboration dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Intra-agency	Units working in isolation with limited intra-agency collaboration.	Some units within the same department collaborate and share models, data, and knowledge. In other cases, collaboration mainly occurs at the analyst level.	Different departments within the agency have strong collaboration with support of different management levels.	Agency documents roles and responsibilities and the associated collaborative processes as part of an integrated framework for the decisionmaking processes.
Inter-agency	Agencies working in isolation with limited inter-agency collaboration.	Agencies collaborate on some projects on a case-by-case basis.	Agencies have processes and memorandums of understanding (MOUs) for regional collaboration and sharing of information, data, resources, training, and models, with the support of management in different partner agencies.	Partner agencies document roles and responsibilities and associated collaborative processes to support regional and statewide modeling practice, harmonized with national and international best practices, as part of an integrated framework for the decisionmaking.

Q6: How do you describe the intra-agency collaboration (collaboration within the agency) related to traffic analysis?

a. The units in our agency are working in isolation with limited intra-agency collaboration.
b. Some units within the same department or unit collaborate and share models, data, and knowledge. In other cases, collaboration mainly occurs at the analyst level.
c. Different departments (e.g., planning, design, operations, data management, and multimodal) within our agency have strong collaboration, and different management levels support the collaboration.
d. Our agency has documented the roles and responsibilities of different units and staff, including the collaborative processes, as part of an integrated framework for the decisionmaking processes.

Q7: How do you describe the inter-agency collaboration (collaboration among agencies) in your region related to traffic analysis?

a. The agencies in our region are working in isolation with limited inter-agency collaboration.
b. The agencies in our region collaborate with each other on some projects on a case-by-case basis.
c. The agencies in our region have processes and MOUs for regional collaboration and sharing of information, data, resources, training, and models, with the support of management in different partner agencies.
d. Partner agencies agree on and document roles, responsibilities, and collaborative processes to support regional and statewide modeling practice, harmonized with national and international best practices, as part of an integrated framework for decisionmaking.

3.4 BUSINESS PROCESS

This section provides a matrix of suggested criteria for each capability level (table 4), followed by multiple-choice questions to confirm the capability within each subdimension, for the business process dimension.

Table 4. Criteria for maturity levels within the business process dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Scoping	No adopted instruction. Project-driven scoping.	Basic instruction, but the agency does not consider it standard operating procedure (SOP)/policy. Limited tool, data, and review requirement consideration in scoping.	Detailed SOP/policies based on latest national findings. Detailed data requirements, tool requirements, and review procedures in scoping.	SOP expands to meet requirements of different functional areas individually in an integrated manner including areas such as long range planning, highway design, transportation system management and operations (TSMO), connected and automated vehicle (CAV), managed lanes, and mobility as a service (MaaS). This level also involves continuously monitoring the national instruction and results from research and development efforts to update our instruction.
Administration	No administration and contracting processes or support. No method for cost estimation.	Started development of procurement process, staff, documentation, and templates. Basic methods for cost estimation.	Established contracting and procurement process, staff, documentation, and templates. Detailed cost estimation methods.	Detailed analysis type-specific procurement and contracting processes, instruction, and templates. Detailed cost estimation methods.
Institutionalization	Ad-hoc institutionalization.	Minimal institutionalization for specific functions.	Established institutionalization in most processes.	Integrated institutionalization to support all processes and decision levels.
Archiving and maintenance	Models or data not maintained or archived.	Ad-hoc maintenance and archiving.	Established process for archiving and sharing models.	Extended process for archiving, sharing, maintaining, and updating models.

Q8: Have you developed and used instruction or SOPs for scoping the analysis projects?

a. No, we do not have instruction or SOPs. We usually depend on project-driven scoping and budget allocation.

b. Yes, we have basic instruction that we developed or adopted from other States. However, we have not reviewed the latest national instruction and research findings to confirm and modify the instruction. The instruction is not an SOP or policy. We do not have a process for detailed consideration of modeling, data requirements, and detailed review procedure in scoping.

c. Yes, we developed detailed SOPs and policy based on latest national findings. We also require the consideration of detailed data requirements, tool requirements, and review procedures in scoping.

d. Yes, we have an extended SOP that, in addition to what is mentioned in (c), meets the requirements of various decision processes associated with different functional areas individually in an integrated manner, including areas such as long range planning, highway design, TSMO, CAV, managed lanes, and MaaS. We also continuously monitor the national instruction and results from research and development efforts to update our instruction.

Q9: Do you have specific procedures, methods, and examples to advise the agency on how to develop a contract with a third party (e.g., request for proposal, scope of work, deliverables schedule, cost proposal, required resources, and acceptance and selection criteria) for transportation system analysis processes?

a. No, we do not have analysis type-specific standard contracting and procurement procedures. This usually occurs at the project level. We also do not have methods to determine the required resources.

b. We have started developing general instruction on contracting and procurement procedures. Some agencies in the State have started using this instruction. We have basic methods to estimate the cost of the project.

c. We have established process, templates, and staff to contract and procure analysis projects. We have detailed methods to determine the required resources for the projects. We use existing data sources to evaluate and update the problem statement in the scope of work, and to inform the data needs for the analysis specified in the scope. Most agencies in the State follow these procedures and methods.

d. We have detailed analysis type-specific procurement and contracting processes, instruction, and templates that State and local agencies use in their procurement processes. We use existing data sources to evaluate and update the problem statement in the scope of work and to inform the data needs for the analysis specified in the scope. We have methods to refine the process, instruction, and templates based on lessons learned.

Q10: Have you institutionalized processes for traffic analysis to support the business process, such as planning, traffic studies, access management, highway design, impact studies, and TSMO?

a. No, we do not have documentation that requires and describes how to use traffic analysis in various business processes.
b. We identified processes for the use of traffic analysis in the manuals or procedures associated in only one or two of these processes.
c. We identified processes for the use of traffic analysis in the manuals for a large portion of our business processes. The use of these methods is required and followed.
d. We have an integrated process for using the analysis in different business processes from long-range planning to detailed operations.

Q11: Do you have a process of archiving and maintaining the analysis files and documents for future use?

a. We do not archive and maintain the utilized data and analysis files.
b. We archive the data collected for the project, the input files, and the output files, in an ad-hoc manner with no data management plan required for archiving and metadata development.
c. We archive the data collected for the project, the input files, and the output files according to industry standard data management plans. Analysts can request these models for use in their projects through a standard procedure.
d. We have a process for archiving, sharing, updating, and maintaining the archived files. We require analysts to share updates to the original models in subsequent projects and incorporate these changes in the archive subject to an approval process.

3.5 SUPPORTING DATA

Table 5 provides a matrix of suggested criteria for each capability level), followed by multiple-choice questions to confirm the capability within each subdimension for the Supporting Data dimension. Although Supporting Data is treated as a subdimension, it is also an important part of other dimensions. In particular, it is important to reference the consideration of supporting data in the scoping and administration subdimensions of the business process dimension (see section 3.4).

Table 5. Criteria for maturity levels within the supporting data dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Data requirement setting	No data requirement consideration.	Data requirement setting in an integrated manner with the analysis plan in some project.	Systematic data requirement setting in an integrated manner with the analysis plan in all projects.	Required documentation confirms that the utilized data quality, and the spatial and temporal resolutions according to the integrated data and analysis plans, are sufficient to meet project requirements, and that the analysis presented in the analysis plan can be supported with the existing data.
Data analytics	No data analytics other than preparing data for inputs and use in calibration.	Occasional use of visualization and analysis tools developed for other purposes.	Regular use of data processing, fusion, visualization, and analysis tools specifically developed to support agency analysis process.	Robust requirements for integrated modeling and data mining and analysis environment in a business intelligence process that considers the specific requirements for the project.
Multiple data sources	Use of traditional data collection methods. No use of new sources of data to supplement analyses.	Use of commonly available automated data sources, such as travel times and origin-destination (O-D) data from third-party vendors and wireless technology readers, to supplement analyses.	Use of data from new and emerging data sources in some projects.	Fusion of data from existing and new data sources.

Table 5. Criteria for maturity levels within the supporting data dimension (continuation).

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Data exchange	No use or very limited use of archived data.	Use of spreadsheets and databases that include data collected and archived for other planning and operation purposes.	Use of State or regional data archives. Ad-hoc download and use of databases. Use of automated tools for data download.	Use of data download, fusion, and analysis tools to process the data from regional archives and prepare the data for use in the analysis. Use of an integrated data archiving and utilization environment that supports the exchange and analysis of data from multiple purposes with a built-in support of analysis, considering the specific needs of various types of analysis.
Data management	Minimal or no data governance and management.	Initiated data governance and management.	Emerging data governance and management.	Robust and integrated data governance and management.

Q12: When collecting data for the project, do you develop a data plan in conjunction with the analysis plan in an integrated manner to identify the data needs in terms of collected data items, accuracy, resolution, timeliness, and coverage?

a. We identify the data needed for the project based on available data from existing sources (and supplemental traffic studies conducted within the project). We do not examine data requirements based on an analysis plan, which would ensure the available and collected data are sufficient to produce acceptable results.

b. We develop the data needs (and ability of data sources to meet the needs) in an integrated manner with the analysis plan in some projects, but do not systematically require it for specific types of projects, and ensure that the data can support all the needs of the analysis, and that the analysis identified in the analysis plan can be done with the data that can be collected. The projects do not generally require examining and ensuring that the data quality and spatial and temporal resolutions are sufficient to meet project requirements.

c. We require the project team to develop data plans for each analysis project in an integrated manner with the analysis plan. We ensure the data plans can support all needs of the analysis specified in the analysis plan, and that the analysis identified in the analysis plan can be done with the data that can be collected. The details of the plan dependent on the project size and scope, and those appropriate and required data needs reflected in the original scope. The agency provides data plan templates for use in projects.

d. In addition to the capabilities in (c) above, the agency requires documentation that confirms that the utilized data quality and spatial and temporal resolutions according to the integrated data and analysis plans are sufficient to meet project requirements and that the analysis presented in the analysis plan can be supported with the existing data.

Q13: When collecting data for the project, do you use data analytic techniques such visualization, statistical analysis, and machine learning to support the analysis, and the decisions made based on the analysis?

a. Our data use is limited to obtaining or calculating the basic measures that can be inputs in the model development, calibration, and validation.

b. We occasionally use data visualization and analysis tools developed for other purposes to examine performance in the network for better calibration and validation of the model.

c. We regularly use data processing, fusion, visualization, and analysis tools specifically developed to support the analysis process. This can include bottleneck characteristics identification tools, reliability estimation tools, and signalized intersection performance tools based on high-resolution controller data. The project team also uses data analysis techniques to identify the need to initiate modeling, and the type of the modeling effort required.

d. The agency has robust requirements for integrated modeling and data mining and analysis environment in a business intelligence process that considers the specific requirements for the project.

Q14: In addition to traffic data collected using existing traffic studies, what other sources of automated data do you use in the analysis?

a. We use only traditional data collection methods. We use some data collected using traffic sensors installed for other purposes.

b. In addition to the capability in (a), we have some use of new sources of data, such as travel times and O-D data from third-party vendors and wireless technology readers, to supplement analyses.

c. In addition to using the data specified in (b) in most projects, we use new and emerging data sources, including vehicle trajectories at both the mesoscopic (selected route by each vehicle) and microscopic levels (car following, lane changing, gap acceptance, etc.), high-resolution controller data, connected vehicle data, and other high-resolution data in some projects.

d. We archive the data from new and emerging data sources, such as vehicle trajectories and other high-resolution in the data archives and apply data fusion and analysis designed to support the analysis and modeling projects.

Q15: What is the mechanism used in data archive and exchange between different data providers and users of the data for modeling?

a. Our use of archived data is either non-existent or very limited.
b. We use spreadsheets and databases that include data collected and archived for other planning and operation purposes. We archive the data in spreadsheets, web-based platforms, and network drives with limited documentation.
c. We have data archives for data collected from our TSMO program and traffic monitoring program that include information, such as travel time/speed, incident, construction, and weather events. The analysts generally download the data archive from cloud data storage in an ad-hoc manner.
d. We use data download, fusion, and analysis tools to process the data from regional archives and prepare the data for use in the analysis. We use an integrated data archiving and utilization environment that supports the exchange and analysis of data from multiple purposes with a built-in support of analysis, considering the specific needs of various types of analysis.

Q16: How does your agency address data governance? Data governance includes managing data availability, quality, usability, integrity, and security from multiple sources.

a. No effort or minimal effort in the region for data governance.
b. We apply data governance principles as part of the management of data collected for other transportation system planning and operations functions.
c. We have emerging systems and policies for data storage and governance with consideration of analysis needs, data quality, and usability for analysis.
d. We have robust staffing, systems, and policies for data storage and governance with consideration of analysis needs. We ensure the quality and usability of data for analysis.

3.6 ANALYSIS PROCESS AND DOCUMENTATION

This section provides a matrix of suggested criteria for each capability level (table 6), followed by multiple-choice questions to confirm the capability within each subdimension, for the analysis process and documentation dimension.

Table 6. Criteria for maturity levels within the analysis process and documentation dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Analysis approach	Simple analyses that take less than a week. Facility-wide and network-wide are not often used.	Analyses that require multiple weeks due to work on scoping, data preparation, data entry, calibration, output processing, or alternatives analysis. Facility-wide and network-wide analysis are done when needed.	Large scale analyses that require multiple months due to the issues mentioned in Level 2 plus large network size, additional analysis and data needs, additional resources, multiple stakeholders, etc.	Capability to conduct multi-scenario analysis, multimodal analysis, travel time reliability analysis, and multi-resolution modeling with a feedback loop when needed.
Advanced and emerging strategies	No consideration of advanced and emerging strategies.	Limited modeling of advanced and emerging strategies, with limited consideration of associated specific requirements.	Modeling advanced and emerging technology applications using national best practices in this modeling.	Modeling advanced and emerging technology applications utilizing approved procedures.
Verification, calibration, and validation (VC&V)	Ad-hoc calibration methods and targets set at the project level. No validation procedure or sensitivity analysis applied. Generally, the analyses use default values for many input parameters of capacity and simulation analysis.	Calibration methodology and targets set at State/agency levels, but no validation procedure applied. This is applied to all analysis types including using analytical and simulation tools. The analyses override the parameters of capacity and simulation analysis based on regional and local conditions.	Calibration is based on analysis-specific targets that are set considering real-world traffic variations based on an approved methodology. Validation is done based on sensitivity analysis. Analysts compare results from multiple tools to enhance the VC&V process.	Analysts ensure that multi-tool analyses converge using documented criteria. The calibration process incorporates high-resolution data.

Table 6. Criteria for maturity levels within the analysis process and documentation dimension (continuation).

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Analysis reporting and documentation	No or limited documentation requirements.	Ad-hoc documentation of analysis activities and results, and the documentation is primarily for users instead of reviewers.	Detailed documentation sufficient for both users and reviewers.	Reviewers follow a documented approach for reviewing models to ensure the analyst performs the analysis according to the requirements.

Q17: What are the traffic analysis approaches you usually take, and how does your agency select the approach for analysis?

a. Our traffic analyses are relatively quick and utilize methods that are easier to use. Our traffic analyses do not require very much time spent on scoping, data processing, data entry, calibration, or preparation of results. The project team selects the analysis approach based on the specific project attributes in an ad-hoc manner. We rarely apply facility-wide or network-wide analysis approaches.

b. Our traffic analyses may involve multiple weeks of work per analysis. We use State DOT-adopted or -developed instruction in selecting the analysis approach. We conduct facility-wide and network-wide analysis when needed.

c. Our traffic analyses often involve multiple months of work per analysis. Our traffic analyses often involve large network sizes, additional analysis and data needs, resources, reviewers, multiple stakeholders, etc.

d. We use multi-scenario modeling, travel time reliability analysis, multimodal analysis, and MRM with a feedback loop when needed. We select the analysis approach based on detailed functional requirements.

Q18: Do you have the knowledge and capabilities required for modeling advanced and emerging strategies and technologies?

a. We have not considered advanced and emerging technology modeling.

b. We have considered advanced and emerging technology modeling but have limited applications. However, we have not yet addressed the specific requirements for this type of modeling.

c. We have worked with planning and operations agencies to model some advanced and emerging technology applications. We have used national best practices in this modeling.

d. We are working closely with planning and operations agencies for consistent modeling of advanced and emerging technology applications to support their decisionmaking process in a formal manner. The agency uses approved procedures to model advanced and emerging technologies.

Q19: How do you calibrate and validate your traffic analyses?

a. We generally set the calibration method and targets at the project level. We do not apply validation procedure/sensitivity analysis to ensure the model does not over fit the calibrated day. Generally, the analysts use default values for many simulation and capacity analysis input parameters.

b. We generally follow the calibration methodology and targets set at the State and/or agency levels but no validation procedure is applied. This is applied to all analysis types, including using analytical and simulation tools. Analysts override the simulation and capacity analysis parameters based on regional and local conditions.

c. Our calibration method is consistent with the *Traffic Analysis Toolbox Volume III* (Wunderlich, Vasudevan, and Wang 2019), in that our method considers the variation in traffic conditions when setting the calibration thresholds. We generally apply project validation in addition to calibration, such as conducting sensitivity analysis to ensure the model does not over fit the calibrated day. Analysts compare results from multiple tools to enhance the VC&V process.

d. We ensure multi-tool analyses converge using documented criteria. We also incorporate high-resolution data (e.g., vehicle trajectories, probe data, automated traffic signal performance measures (ATSPM)) into the calibration process.

Q20: How are the results of the analysis documented and examined to ensure the quality of the analysis?

a. We produce either no documentation or limited documentation of the analysis method and results.

b. We require documentation of analysis activities and results in sufficient levels of detail for the user of the results of the analysis. However, we believe this documentation is oriented to the users of the analysis results, rather than to the reviewers of the analysis.

c. We require documentation of analysis activities and results in sufficient levels of detail for both the reviewer of the analysis (to validate various steps of the analysis) and the user of the analysis results.

d. We require documentation of analysis activities and results in sufficient levels of detail for both the reviewer of the analysis (to validate various steps of the analysis) and the user of the analysis results. The reviewers follow a documented approach for reviewing models to ensure the analyst performs the analysis according to the requirements.

3.7 TOOL AVAILABILITY AND CAPABILITY

The following section provides a matrix of suggested criteria for each capability level (table 7), followed by multiple-choice questions to confirm the capability within each subdimension, for the tool availability and capability dimension.

Table 7. Criteria for maturity levels within the tool availability and capability dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Tool selection	Ad-hoc selection by project public agency manager and project consultant.	Selection based on national, statewide, or agency-wide instruction. Selection constrained by available tools, knowledge, and experience.	Tool selection based on detailed agency-wide criteria and analysis type-specific criteria. Selection not constrained by available tools, knowledge, and experience.	Tool selection reflects agency staff's direct experience with using a wide variety of analysis tools from a wide variety of developers and vendors. Agency staff are also familiar with the developers' future plans and directions for these tools.
Tool availability	Agency staff only have access to one preferred tool, or are uncomfortable with the thought of using other tools beyond their preferred tool.	Agency staff only have access to a few preferred tools (possibly from the same vendor), or are uncomfortable with the thought of using other tools beyond their few preferred tools. Limited use of supplemental or add-on tools.	Agency staff have access to a variety of tools for most types of traffic analysis. However, for certain types of traffic analysis, tool availability may be limited or sub-optimal. Limited use of data analytics tools to assess and improve the quality of the data used for traffic analysis.	Full access to a wide variety of traffic analysis tools and data analytics tools from a wide variety of developers and vendors, which can be utilized based on project requirements.

Q21: How do you select the tool(s) for your traffic analyses?

a. The selection of the specific tool for the analysis is ad-hoc by the project public agency manager and the project consultant.
b. Tool selection reflects national, statewide or agency-wide instruction. However, the selection is constrained by the available tools, knowledge, and experience.
c. Tool selection reflects agency-wide and analysis type-specific criteria, in addition to requirements and criteria written specifically for the project. In general, the selection is not constrained by the available tools, knowledge, and experience.
d. Tool selection reflects agency staff's direct experience with using a wide variety of analysis tools from a wide variety of developers and vendors. Agency staff are also familiar with the developers' future plans and directions for these tools.

Q22: How do you describe your core capabilities in using analysis tools and the availability of these tools considering different levels ranging from sketch planning tools to microscopic simulation tools?

a. Agency staff only have access to one preferred tool, or are uncomfortable with the thought of using other tools beyond their preferred tool. We have the capability to regularly use less-complex tools and limited capabilities to use more advanced tools.
b. Agency staff only have access to a few preferred tools (possibly from the same vendor), or are uncomfortable with using other tools beyond their few preferred tools. We routinely use deterministic and/or microscopic simulation tools to meet project objectives. There is some ad-hoc use of DTA for a very limited number of projects. We have very limited supporting tools to assist in developing, calibrating, validating, and using the results of the models.
c. Agency staff have access to a variety of tools for most types of traffic analysis. However, for certain types of traffic analysis, tool availability may be limited or sub-optimal. We routinely use deterministic and/or microscopic simulation tools and have the capabilities to use DTA and MRM to meet project objectives. We have limited use of supporting tools to assist in developing, calibrating, validating, and using the results of the models.
d. Agency staff have full access to a wide variety of traffic analysis tools and data analytics tools from a wide variety of developers and vendors, which can be utilized based on project requirements. We have the capability to use modeling tools of different resolution and data analytic tools including statistical analysis, machine learning, and visualization in an integrated analysis and decision support environment. Supporting tools are integrated into the environment to assist in developing, calibrating, validating, and using the results of the models.

3.8 PERFORMANCE ESTIMATION AND MEASURES

The following section provides a matrix of suggested criteria for each capability level (table 8), followed by multiple-choice questions to confirm the capability within each subdimension, for the performance estimation and measures dimension.

Table 8. Criteria for maturity levels within the performance estimation and measures dimension.

Subdimension	Level 1–Performed	Level 2–Initiated and Managed	Level 3–Established	Level 4–Integrated and Optimized
Measure selection	Ad-hoc performance measure selection on a project-by-project basis.	Use of general instruction and established practice for measure selection.	Selection of measures based on predefined metrics identified for each type of project.	Selection of measures using an integrated process to support different levels of decisions in the region. Mapping of cause-and-effect relationships among measures used at different levels of the agency.
Measure estimation	Use of performance measures produced as outputs of the analysis tools. Limited understanding of measure definitions and calculations in different tools.	Recognition of differences in measures estimated by different tools, and consideration of this in the analysis.	Specified definitions and methods of calculating performance measures for different uses of analysis to support decision processes. Calculation of mobility, reliability, safety, emission, and equity measures.	Calculation of multimodal measures based on various model outputs. Use of microscopic level trajectories and APIs to estimate performance metrics.
Measure use	Analysts report measures in a basic format without significant statistical analysis and without showing a distribution of possible outcomes.	Analysts use statistical analysis and visualization to compare alternatives. Analysts use deterministic analysis to assess the need for simulation analysis.	Analysts conduct sensitivity testing to determine the effect of modeling assumptions on analysis results. Analysts obtain measures and visualizations that reflect the buildup and dissipation of congestion over space and time. When conducting deterministic analysis, we develop multiple input scenarios to obtain a distribution of possible outcomes.	Analysts use measures in an integrated business intelligence framework. Analysts use analysis results combined with real-world data monitoring to trigger further analysis.

Q23: How do you select performance measures for use in reporting the analysis results?

a. We select the performance measures in an ad-hoc fashion on a project-by-project basis.
b. We use general instruction and established practice for the selection and utilization of performance measure reported in the outputs of deterministic and simulation tools. Where possible, we estimate the selected measures for analysis based on the collected data according to the scoping process, to ensure that the estimation of these measures is verified.
c. We select measures based on predetermined metrics identified for each type of project, considering the process supported by the project (planning, design, management, operations), type of the decision, and level of analysis used for each subnetwork (macroscopic, mesoscopic, microscopic).
d. We select and define performance metrics using an integrated process to support different levels of decisions in the region, from strategic to tactical to operational. We develop a mapping between the measures used at different levels of the agencies and the cause-and-effect relationships among these measures.

Q24: How do you describe the method used in your estimation of performance measures based on the analysis outputs?

a. We use performance measures produced as outputs of the analysis tool, plus measures that the agency is already using. However, there is a limited understanding of measure definitions and calculations in different tools and the differences in estimation among the different tools. There is also limited identification of performance measures based on the purpose and need of the project.
b. We recognize the differences in the measures estimated by different tools and consider this in our analysis. Our selected measures reflect the purpose and need of the project.
c. Building on the capability in (b), we specify definitions and methods of calculating performance measures for different uses of analysis to support decision processes. The definitions include the analysis interval and period, required data and data sources, and calculation formulas. We use these definitions to calculate the measures based on field data, as well as models, considering the inconsistencies in the definition of measures in different modeling tools. In addition to mobility measures, we calculate reliability, safety, emission, and equity measures.
d. In addition to the capability in (c), we calculate multimodal measures based on various model outputs. We recognize that we cannot calculate all measures based on the measures that are output from the tools. Thus, we use models and tools for the calculation of the measures based on trajectory data at the microscopic level, and in some cases use APIs to estimate the performance metrics. The calculation of measures for the different decision levels and functions are consistent with each other.

Q25: How do you use the estimated performance measures obtained based on the data and model analysis outputs?

a. We report the measures in a basic format without statistical analysis, and without showing a distribution of possible outcomes.
b. We use hypothesis testing, statistical analysis, and visualization to compare alternatives. When considering the use of simulation, we use deterministic analysis results to determine whether there is a need for simulation analysis. When conducting microsimulation, we require the use of statistical equations to estimate the required number of replications based on the variations in the results from the simulation.
c. In addition to the capabilities in (b), we conduct sensitivity testing to determine the implication of changes in the modeling assumptions on the analysis results. We obtain measures (e.g., residual delay, latent delay, unmet demand) and visualizations (e.g., heat maps, queue accumulation polygons) that reflect the buildup and dissipation of congestion across multiple roadway segments and time periods. When conducting deterministic analysis, we develop multiple input scenarios based on varying operating conditions (e.g., demand variation, weather, incidents, special events) to obtain a distribution of possible outcomes.
d. In addition to the capabilities in (c), we use the measures in an integrated business intelligence framework. We use the analysis results combined with real-world data monitoring to trigger further analysis. As part of our regional data archiving and monitoring, we have methods to flag locations that potentially require further analysis.

CHAPTER 4. IDENTIFICATION OF ACTIONS TO IMPROVE CAPABILITY

Once the agency identifies its current level of maturity using chapter 3, an agency can use chapter 4 to understand the high-level actions needed to advance to the next level by sub-dimension. These actions are suggestions as opposed to required actions. Agency stakeholders can develop customized actions for their specific needs and agency constraints.

This Traffic Analysis CMF suggests methods, processes, and approaches to advance to the next level of capability for each subdimension of the eight dimensions. The framework allows for development of consensus around needed and feasible agency improvements to continuously improve traffic analysis capabilities. The CMF enables agencies to identify and develop actions that will move them to the next level in each dimension. Selecting actions also helps agencies focus on identified weakest links in developing their capabilities.

The following sections provide a list of customizable actions for moving between different levels in each dimension. The actions go from level 1 to level 2, from level 2 to level 3, and from level 3 to level 4 for each subdimension. From the list, agencies can select the set of actions that best meets the needs of their region and agency. Note that these are just possible actions. Agencies can develop their own actions based on their own needs and constraints. Agencies do not need to rigidly follow the actions presented in this section. As this is a self-assessment, agency staff are the ones best positioned to identify which actions will be most effective and feasible for their agency.

Agencies should use a collaborative process to select and customize action details. Stakeholders can identify, filter, and compile a set of actions appropriate to the region or agency to advance from one level to the next. Follow-up meetings can identify how to implement the actions and review the consequences of the actions.

4.1 CULTURE

The following section provides a matrix of suggested actions to improve capability level (table 9), followed by a more detailed discussion of these suggested actions, for the culture dimension.

Table 9. Actions to advance to the next level for the culture dimension.

Subdimension	Level 1 to 2	Level 2 to 3	Level 3 to 4
Understanding role and value	Improve lower-level managers' understanding	Engage upper management	Develop an integrated understanding
Cost acceptance	Obtain limited funding	Have funding available to meet project objectives	Have extra funding available for advanced modeling
Management and operation modeling	Recognize the importance of analyzing some basic traffic control strategies	Recognize the importance of modeling advanced traffic management and control strategies	Recognize the importance of off-line and real-time modeling combined with data analytics to support traffic analysis, management, and control
Collaborative culture	Develop culture of collaboration between analysts	Develop culture of collaboration between analysts and different levels of management	Promote commitment to support and invest in advancing and maintaining collaboration

Improve Lower-Level Managers' Understanding

This action intends to achieve the following capability maturity improvement:

- From level 1: Little understanding of the role and value of traffic analysis by the decisionmakers. Activities are champion driven
- To level 2: Lower-level managers understand importance of enhanced traffic analysis capabilities

This involves engaging lower-level managers in developing an understanding of the role and value of analysis by establishing a process that tracks traffic analysis activities/projects, documenting and reporting measurable benefits from these projects to key staff and lower-level managers. This potential action continuously enhances the understanding of analysis capabilities at all levels and demonstrates the benefits of these analysis capabilities.

Engage Upper Management

This action intends to achieve the following capability maturity improvement:

- From level 2: Lower-level managers understand importance of enhanced traffic analysis capabilities
- To level 3: In addition to the capability in level 2, upper management understands the need to support and invest in traffic analysis practices, and in advancing these capabilities to reach higher levels of maturity

In addition to improving lower-level managers' understanding of the roles and value of traffic analysis and modeling, data analysts and lower-level managers work together to develop a business case that identifies why investment in traffic analysis and modeling practices is important. The lower-level managers conduct meetings with upper management to discuss traffic analysis need and benefits. The lower-level managers obtain buy-in and support for investing and advancing modeling capabilities.

Develop an Integrated Understanding

This action intends to achieve the following capability maturity improvement:

- From level 3: In addition to the capability in level 2, upper management understands the need to support and invest in traffic analysis practices, and in advancing these capabilities to reach higher levels of maturity
- To level 4: Integrated understanding of the objectives, measures of success, and targets of modeling use by managers at different levels

This action expands the effort described in the previous (level 2 to level 3) to a more systematic way of engaging managers at different levels. This potential action develops an integrated understanding of the objectives, success measures, and modeling targets used by managers at different levels by establishing a traffic analysis body of knowledge. This establishes a mechanism to measure, report, and share lessons learned. It creates a library of resources related to all aspects of traffic analysis and incorporates the library into relevant training plans.

Obtain Limited Funding

This action intends to achieve the following capability maturity improvement:

- From level 1: Analysts find significant obstacles to get funding for the use of traffic analysis when needed
- To level 2: Analysts can generally get funding for simulation modeling when needed only in some cases, and up to a certain limit

This potential action will engage the management team on understanding the importance and benefits of investing in traffic analysis. The action will develop a mechanism to quantify the

return of investment of traffic analysis and share that with the management team to obtain buy-in and funding support.

Have Funding Available to Meet Project Objectives

This action intends to achieve the following capability maturity improvement:

- From level 2: Analysts can generally get funding for traffic analysis when needed only in some cases, and up to a certain limit
- To level 3: Analysts can get funding for traffic analysis whenever such analysis is required to meet the project objectives

The traffic analysis champion develops a clear business case to demonstrate the necessity of conducting traffic analysis and modeling, when applicable, to meet project objectives. The champion articulates how project objectives may suffer if no funding is available for conducting traffic analysis. The champion defines a set of criteria when traffic analysis and modeling will be necessary and beneficial. The champion works with management teams to ensure funding is available for traffic analysis and modeling when these criteria are met.

Have Extra Funding Available for Advanced Modeling

This action intends to achieve the following capability maturity improvement:

- From level 3: Analysts can get funding for traffic analysis and modeling whenever such analysis and modeling is required to meet the project objectives
- To level 4: Analysts can get the extra funding required for analysis of advanced strategies that require advanced techniques such as multi-scenario modeling, multi-period modeling, DTA, MRM, and calibration based on high-resolution data

The traffic analysis specialists identify a champion to lead the advancement of analysis and modeling techniques. The champion engages the management team on understanding the necessity of using advanced techniques to support the analysis of advanced strategies and demonstrate quantitative and qualitative benefits of advanced techniques. The champion defines clear criteria when advanced techniques will be beneficial and make sure funding is available when these criteria are met.

Recognize the Importance of Analyzing Some Basic Traffic Control Strategies

This action intends to achieve the following capability maturity improvement:

- From level 1: Decisionmakers do not think that analysis of traffic control strategies is needed
- To level 2: Decisionmakers recognize the importance of analyzing some traffic control strategies like signal priority and managed lanes

This action involves gathering and developing case studies to help decisionmakers understand the rationale and benefits of analyzing basic traffic control strategies, such as signal priority and managed lanes. It involves developing standard procedures for analyzing these common applications. The action helps decisionmakers understand that traffic analysis and modeling can be a cost-effective tool to help measure some basic traffic control strategy impacts and can be very important to its success.

Recognize the Importance of Analyzing Advanced Traffic Management and Control Strategies

This action intends to achieve the following capability maturity improvement:

- From level 2: Decisionmakers recognize the importance of analyzing some traffic control strategies like signal priority and managed lanes
- To level 3: Decisionmakers realize the importance of analyzing traffic control strategies, such as freeway and arterial active transportation and management, incident management, and CAV DMAs

This action encourages the gathering and development of case studies. The studies help decisionmakers realize the importance and benefits of analyzing a wide range of traffic control strategies. These strategies include active transportation and demand management (ATDM) (see figure 12), integrated corridor management, incident management, and CAV DMAs. This action develops standard procedures for analyzing these more advanced traffic control strategies. These procedures help the decisionmakers understand what resources will be needed to carry out these analysis activities.

Source: FHWA.

Figure 12. Photo. Variable speed limit deployment.

Recognize the Importance of Off-Line and Real-Time Modeling Combined with Data Analytics to Support Traffic Analysis, Management, and Control

This action intends to achieve the following capability maturity improvement:

- From level 3: Decisionmakers realize the importance of modeling TSMO strategies, such as freeway and arterial active transportation and management, incident management, and CAV DMAs

- To level 4: Decisionmakers recognize the importance of off-line and real-time modeling combined with data analytics to support analysis of advanced and emerging strategies

This action involves gathering and developing case studies to demonstrate and help decisionmakers understand when, why, and how to use off-line and real-time modeling combined with data analytics to support TSMO. It further involves developing standard procedures of using off-line and real-time modeling combined with data analytics to support analysis of advanced and emerging strategies. It further involves developing a comprehensive traffic analysis program and clearly defining how this program supports other programs and projects.

Develop Culture of Collaboration among Analysts

This action intends to achieve the following capability maturity improvement:

- From level 1: There is no culture of collaboration in the agency
- To level 2: There is a strong culture of collaboration between analysts; however, this collaboration mainly occurs at the analyst levels

This action involves developing a program to promote data and knowledge sharing among analysts within the agency. Documenting and sharing resources and lessons learned among analysts promotes collaboration and innovation. It also helps to improve the efficiency of traffic analysis practices within the agency.

Develop Culture of Collaboration among Analysts and Different Levels of Management

This action intends to achieve the following capability maturity improvement:

- From level 2: There is a strong culture of collaboration between analysts; however, this collaboration mainly occurs at the analyst levels
- To level 3: There is a strong culture of collaboration that involves the analysts and the different levels of management

This action focuses on engaging different levels of management in the traffic analysis data, knowledge, and experience sharing program by having regular meetings with different levels of management. The action helps agency staff to understand accomplishments, issues, lessons learned, and the benefits of collaboration.

Promote Commitment to Support and Invest in Advancing and Maintaining Collaboration

This action intends to achieve the following capability maturity improvement:

- From level 3: There is a strong culture of collaboration that involves the analysts and the different levels of management

- To level 4: There is a strong culture of collaboration and strong commitment to support and invest in advancing and maintaining the collaboration as part of integrated framework of analysis support of the decisionmaking process

This action includes developing an approved process for active engagement and collaboration with agency groups and partner agencies. This action ensures that the agency strategic plan includes linkages between traffic analysis and core functions. This action will not only promote a strong culture of collaboration among analyst and different levels of management, but will also help the agency invest in advancing and maintaining this collaborative culture to benefit the entire agency.

4.2 WORKFORCE

The following section provides a matrix of suggested actions to improve capability level (table 10), followed by a more detailed discussion of these suggested actions, for the workforce dimension.

Table 10. Actions to advance to the next level for the workforce dimension.

Subdimension	Level 1 to 2	Level 2 to 3	Level 3 to 4
Workforce development	Initiate staff development in limited agency units	Establish staff development in additional parts of the organization	Establish robust staff development with external support and involvement
Current staffing knowledge, skills, and abilities (KSAs)	Initiate review capabilities	Establish good review and analysis capabilities	Provide advanced analysis and modeling capabilities

Initiate Staff Development in Limited Agency Units

This action intends to achieve the following capability maturity improvement:

- From level 1: No formal effort for staff development, training, recruitment, and retention
- To level 2: One or more units assigned to grow practices in the organization; organize workshops and seminars to build the staff capabilities

This action item identifies one or more units within the agency to grow traffic analysis and modeling practices. These specific units should regularly organize workshops and seminars to provide technical instruction on performing traffic analysis and modeling. The action will support and invest in these units.

Establish Staff Development in Additional Parts of the Organization

This action intends to achieve the following capability maturity improvement:

- From level 2: One or more units assigned to grow practices in the organization; organize workshops and seminars to build the staff capabilities

- To level 3: Accelerating staff development, training, recruitment, and retention

This action expands the effort described in the previous action (from level 1 to level 2) beyond a limited number of specific units to a bigger part of the organization by engaging data and modeling analysts and staff from other supporting units in staff development, training and recruiting activities. This includes establishing/updating traffic analysis body of knowledge, developing a robust training program, and engaging management from a larger part of the organization (e.g., all relevant units) to develop a consistent staff detention plan across different units.

Establish Robust Staff Development with External Support and Involvement

This action intends to achieve the following capability maturity improvement:

- From level 3: Accelerating staff development, training, recruitment, and retention
- To level 4: Robust staff development, training, recruitment, and retention

This action further expands the effort described in the previous (level 2 to level 3) to develop a robust and systematic workforce development plan to guide staff development, training, recruitment, and retention across the entire organization. This plan will also identify strategies and approaches to engage external modeling community to support the workforce development. The agency will update this plan regularly based on lessons learned and agency needs.

Initiate Review Capabilities

This action intends to achieve the following capability maturity improvement:

- From level 1: Skills to develop models in consultants; limited skills to approve and use model results for agency decisionmaking
- To level 2: Provide limited training; some review capabilities in public agencies, but still reliance on third-party reviews

This action item involves not only contracting with consultants to help review modeling results when no such capabilities are available within the organization itself, but also develop training programs by working with consultants to help staff build the capability of reviewing traffic analysis results and gaining knowledge on specific tools. For example, agencies can develop standard checklists to assist staff review traffic analysis models.

Establish Good Review and Analysis Capabilities

This action intends to achieve the following capability maturity improvement:

- From level 2: Provide limited training; some review capabilities in public agencies, but still reliance on third-party reviews

- To level 3: Good experience in the traffic analysis and modeling tools, and can review software inputs and outputs; training on basic and advanced topics on the development and review of models

This action includes either recruiting staff with good experience or training existing staff to advance their capabilities in traffic analysis and modeling tools, to make sure they can review software inputs and outputs without third-party help. Agencies can conduct training through developing seminars and workshops covering basic and advanced modeling topics on the development and review of traffic analysis tools and models.

Provide Advanced Analysis and Modeling Capabilities

This action intends to achieve the following capability maturity improvement:

- From level 3: Good experience in the traffic analysis and modeling tools, and can review software inputs and outputs; training on basic and advanced topics on the development and review of models
- To level 4: Staff follows, participates in, understands, and incorporates the latest national and international developments and incorporate lessons learned in their AMS

This action involves developing a robust training program to keep staff updated with the latest national and international developments of traffic AMS and offering analysts and managers financial and administrative support and the authority to participate in national pilot and pooled-fund projects to assess and learn new and emerging traffic analysis techniques.

4.3 COLLABORATION

The following section provides a matrix of suggested actions to improve capability level (table 11), followed by a more detailed discussion of these suggested actions, for the collaboration dimension.

Table 11. Actions to advance to the next level for the collaboration dimension.

Subdimension	Level 1 to 2	Level 2 to 3	Level 3 to 4
Intra-agency	Ensure intra-department collaboration	Ensure inter-department collaboration	Ensure integrated collaborative process
Inter-agency	Initiate inter-agency collaboration	Establish formal inter-agency collaboration process supported by memorandums of understanding (MOUs)	Advance regional collaboration harmonized with national and international best practices

Ensure Intra-department Collaboration

This action intends to achieve the following capability maturity improvement:

- From level 1: Units working in isolation with limited intra-agency collaboration
- To level 2: Units within the same department collaborating and sharing models, data, and knowledge

This action item involves creating a list of conditions/events where collaboration among different units within the same department is mutually beneficial and establish standard procedure (e.g., security, formats, archiving) of collaborating and sharing within the same department.

Ensure Inter-department Collaboration

This action intends to achieve the following capability maturity improvement:

- From level 2: Units within the same department collaborating and sharing models, data, and knowledge
- To level 3: Different departments within the agencies have strong collaboration with the support of different management levels

This action expands the effort described in the previous action (from level 1 to level 2) beyond the units within the same department to different departments. It creates a list of conditions and events where collaboration across different departments is mutually beneficial, develops agreements with different departments to regulate the collaboration, and keeps different management levels engaged while collaborating with different departments.

Ensure Integrated Collaborative Process

This action intends to achieve the following capability maturity improvement:

- From level 3: Different departments within the agencies have strong collaboration with the support of different management levels
- To level 4: Agency documents roles and responsibilities and the associated collaborative processes as part of an integrated framework for the decisionmaking processes

This action includes developing traffic analysis collaboration documents (e.g., agreements or MOUs) to identify roles and responsibilities among different departments and units within the organization and specify how these collaborative processes should be integrated into the decisionmaking processes. Establishing a steering committee to guide and evaluate these collaborative processes and engage management level from different departments to obtain buy-in and support from them.

Initiate Inter-agency Collaboration

This action intends to achieve the following capability maturity improvement:

- From level 1: Agencies working in isolation with limited inter-agency collaboration
- To level 2: Agencies collaborate with each other on projects on a case-by-case basis

This action item involves identifying agencies involved in the same project and developing roles, responsibilities, and conditions/rules for sharing data, modeling, and analysis with those agencies to support the objective of the project.

Establish Formal Inter-agency Collaboration Process Supported by Memorandums of Understanding

This action intends to achieve the following capability maturity improvement:

- From level 2: Agencies collaborate with each other on projects on a case-by-case basis
- To level 3: Agencies have processes and MOUs for regional collaboration and sharing of information, data, resources, training, and models with the support of management in different agencies

This action includes developing formal collaboration process documents and MOU for inter-agency collaboration. It involves sharing of information, data, resources, training, and models with the support of management in different agencies. It further involves having regular meetings with different agencies to report success, identifying places for improvement to support better collaboration in the future, and conducting joint training exercises to build relationships.

Advance Regional Collaboration Harmonized with National and International Best Practices

This action intends to achieve the following capability maturity improvement:

- From level 3: Agencies have processes and MOUs for regional collaboration and sharing of information, data, resources, training, and models with the support of management in different agencies
- To level 4: Partner agencies document roles and responsibilities and the associated collaborative processes to support regional and statewide modeling practice, harmonized with national and international best practices, as part of an integrated framework for the decisionmaking

This action involves working with partner agencies to document roles, responsibilities, and associated processes to support regional and statewide modeling practices. This could include the following:

- Formalizing agreements once all agencies are comfortable with them
- Promoting improved collaboration (in data, model, and resource sharing) beyond regions through extensive outreach efforts
- Working with local universities to research traffic analysis issues

- Facilitating peer-to-peer exchanges and engagement to gain competencies and exposure to previous experiences
- Participating in federal pilot and pooled-fund projects to keep up with national and international best practices

4.4 BUSINESS PROCESS

The following section provides a matrix of suggested actions to improve capability level (table 12), followed by a more detailed discussion of these suggested actions, for the business process dimension.

Table 12. Actions to advance to the next level for the business process dimension.

Subdimension	Level 1to 2	Level 2 to 3	Level 3 to 4
Scoping	Develop or adopt scoping instruction	Adopt detailed scoping instruction to act as a policy for the analysis	Update scoping to consider the requirements of various decision processes
Administration	Start developing administration and contracting support for traffic analysis	Establish administration and contracting support for traffic analysis	Refine administration and contracting support for traffic analysis
Institutionalization	Initialize institutionalization process	Extend institutionalization process	Integrate institutionalization process
Archiving and maintenance	Include in instruction	Require data archiving and management plan	Require maintenance plan

Develop or Adopt Scoping Instruction

This action intends to achieve the following capability maturity improvement:

- From level 1: No adopted instruction; project-driven scoping
- To level 2: Basic instruction, but the agency does not consider the instruction as SOP or policy; limited consideration of tool, data, and review requirements in scoping

The agency develops or adopts basic instruction for scoping traffic analysis projects. As described in FHWA's *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* (Wunderlich, Alexiadis, and Wang 2017), the minimum instruction includes defining the project purpose, identifying temporal and spatial scopes, selecting the analysis approach, selecting the analysis tool, and estimating staff time. To increase use of the instruction, the agency will perform significant outreach to the analysis and modeling staff and will provide training on the instruction. This will provide the foundation for identifying project-specific performance measures, refining alternative mitigation strategies and data needs, selecting tools, and estimating costs and schedules. Such instruction is key in developing the scope of services.

Adopt Detailed Scoping Instruction to Act as a Policy for the Analysis

This action intends to achieve the following capability maturity improvement:

- From level 2: Basic instruction, but the agency does not consider the instruction as SOP or policy; limited consideration of tool, data, and review requirements in scoping
- To level 3: Detailed SOP/policies based on latest national findings; detailed consideration of data and tools in scoping

This action expands the scoping procedure described in the previous (level 1 to level 2) action to a detailed scoping procedure. The agency can use FHWA's scoping guide (Wunderlich, Alexiadis, and Wang 2017) as a basis for the development of scoping instruction or policy. According to the scoping guide, analysts should use system performance measures based on real-world data for early diagnostic activities to develop and prioritize the problem statements associated with a high-priority concept. The agency can use the procedure as a policy or as a required SOP for conducting traffic analysis. To ensure the use of the SOP, the agency provides significant outreach and training to the modeling staff on the standard procedures.

The agency assigns staff with the responsibility for developing, maintaining, and updating the SOP. The staff considers national efforts to identify analysis instruction, development, research findings, plus the latest development and testing efforts. Staff may also share information with other States that are developing and adopting analysis approaches. Agency staff may interact with organizations and committees that focus on traffic analysis and modeling, such as the Simulation and Capacity Analysis User Group (SimCap) and committees of the TRB, including the Traffic Simulation Committee, the Highway Capacity and Quality of Service Committee, and the Joint Simulation Subcommittee. Given that traffic analysis tools, procedures, and data sources are evolving, it is helpful for staff to get involved and obtain the latest information to inform their instruction. Many new sources and development efforts at the national and State levels can help the agency develop and enhance their instruction, including the TSSM (List et al., Forthcoming).

Update Scoping to Consider Decision Processes

This action intends to achieve the following capability maturity improvement:

- From level 3: Detailed SOP/policies based on latest national findings; detailed consideration of data and tool in scoping
- To level 4: The SOP expands to meet the requirements of various decision processes, including those for advanced and emerging strategies and technologies

Existing State instruction on scoping traffic analysis projects focuses on the analysis of traditional capacity improvements for transportation systems. The analysis of advanced and emerging technologies will add a significant complexity to the scoping. The consideration of such strategies will influence all aspects of scoping, including the modeling approach, temporal and spatial extents, need for multi-scenario modeling, need for MRM, type of commercially available tools and extensions to these tools, performance measures to assess, and even model

calibration and validation methods. This, in turn, will influence the cost, schedule, and required qualifications of the team who will conduct the analysis.

Start Developing Administrative and Contracting Support for Traffic Analysis

This action intends to achieve the following capability maturity improvement:

- From level 1: No administration and contracting processes or support; no method for cost estimation
- To level 2: Developing contracting and procurement staff, documentation, and templates; basic methods for cost estimation

In this action, the agency begins to provide dedicated staff for traffic analysis contracting, pricing, and procurement. The dedicated staff begins to develop template documents. The agency uses general and simple cost estimation methods.

Establish Administration and Support for Traffic Analysis

This action intends to achieve the following capability maturity improvement:

- From level 2: Developing administration staff, documentation, and templates; basic methods for cost estimation
- To level 3: Established administration staff, documentation, and templates; detailed cost estimation methods

In this action, the agency will establish procurement processes and staff for traffic analysis contracting, pricing, and procurement. The agency provides mature documentation to support procurement and contracting. The staff also adopts more detailed cost estimation methods (e.g., parametric, task decomposition, analogy) for complex analysis projects.

Refine Administration Support for Traffic Analysis

In this action, the agency has a process to refine the procurement process and staff for traffic analysis contracting, pricing, and procurement based on national, State, and local experience and lessons learned. The refined support can have analysis type-specific (e.g., TSMO, planning, geometric design improvement analysis) procurement and contracting process, instruction, and produced templates that State and local agencies use in their procurement processes.

Initialize Institutionalization Process

This action intends to achieve the following capability maturity improvement:

- From level 1: No institutionalization
- To level 2: Minimal institutionalization for specific functions

The unit responsible for advancing traffic analysis in the agency will coordinate with the departments that have previously used traffic analysis for decision support. This can include

departments responsible for developing master plans, geometric designs, and signal timing improvements for transportation facilities. Agencies will identify the analysis approach to support each decision. Starting the institutionalization of traffic analysis in applications that frequently use traffic analysis is a first step to achieve agency-wide improvement. Some agencies have already included text in some of their planning and design manuals to ensure effective and consistent analysis for specific functions of the analysis.

Extend Institutionalization Process

This action intends to achieve the following capability maturity improvement:

- From level 2: Minimal institutionalization for specific functions
- To level 3: Established institutionalization in most processes

The unit responsible for advancing traffic analysis coordinates with the remaining departments responsible for functions that can benefit from traffic analysis. However, these departments (e.g., TSMO and multimodal departments) have not institutionalized the use of analysis in the decisions associated with these functions. Agencies will identify all key decisions, the level of analysis, the analysis approach, and performance measures to support each decision. The agency will also have a process to update such details based on lessons learned and new findings. This step ensures effective traffic analysis for all agency decisions that require traffic analysis.

Integrate Institutionalization Process

This action intends to achieve the following capability maturity improvement:

- From level 3: Established institutionalization in most processes
- To level 4: Integrated institutionalization to support all processes and decision levels

The unit responsible for advancing traffic analysis coordinates with the remaining departments to institutionalize an integrated analysis and decision processes across all levels and functions of the agency. This can include the institutionalization of a business intelligence strategy to define, standardize, and integrate data analytics and modeling approaches to support various decisions including planning, design, engineering, operations, and management. The formalized development and use of business intelligence evolves from traffic analysis applications in individual departments to across the organization and potential partner agencies. The agency aligns and coordinates the use of business intelligence across different decision levels (strategic, tactical, and operational).

Include in Instruction

This action intends to achieve the following capability maturity improvement:

- From level 1: Models not maintained or archived
- To level 2: Ad-hoc maintenance and archiving

This action involves the inclusion of text in the agency-adopted traffic analysis instruction for archiving and maintaining the developed models. This action will encourage the practice of archiving and maintaining the developed models.

Require Data Archiving and Management Plan

This action intends to achieve the following capability maturity improvement:

- From level 2: Ad-hoc maintenance and archiving
- To level 3: Establish process for archiving and sharing models

This action involves including the following archiving requirements in SOPs based on a data management plan developed according to industry standards: project documentation, real-world data collected for the project, input files, and output files. Analysts can request these models for use in future projects through a standard procedure. This action will ensure the analysts archive developed models in an effective and consistent manner.

Require Maintenance Plan

This action intends to achieve the following capability maturity improvement:

- From level 3: Established process for archiving and sharing models
- To level 4: Extended process for archiving, sharing, maintaining, and updating models

This action involves including in SOPs the requirement for maintaining and updating project documentation, real-world data collected for the project, input files, and output files, in addition to archiving these items according to a documented process. The agency requires analysts to share updates to the original models in subsequent projects and incorporate these changes into the archive, subject to an approval process. Analysts can request these models for use in future projects through a standard procedure. This may include updating multiresolution model networks and regional demand forecasting models. This action will ensure the analysts maintain the developed models in an effective and consistent manner.

4.5 SUPPORTING DATA

The following section provides a matrix of suggested actions to improve capability level (table 13), followed by a more detailed discussion of these suggested actions, for the supporting data dimension.

Table 13. Actions to advance to the next level for the supporting data dimension.

Subdimension	Level 1 to 2	Level 2 to 3	Level 3 to 4
Data requirement setting	Include data requirements in instruction document	Provide detailed data requirement policies	Specify filtering algorithms and data quality requirements
Data analytics	Use general purpose tools	Develop and adopt data tools	Use integrated modeling and data environment
Multiple data sources	Use data from commonly available sources	Use data from new and emerging sources	Fuse data from multiple sources
Data exchange	Archive data	Provide automated data access tools	Implement integrated data archiving and analytic environment
Data management and governance	Initiate data governance	Establish emerging data governance and management	Provide integrated data governance and management

Include Data Requirements in Instruction Document

This action intends to achieve the following capability maturity improvement:

- From level 1: No data requirement consideration
- To level 2: Ad-hoc data requirement setting

This action involves including in the agency-adopted traffic analysis instruction the provision for a data requirement plan. This plan will specify data needs, including the resolution and accuracy of the data. The instruction will advise analysts to use descriptive statistics for data variation in time and space to identify discrepancies, missing data, abnormalities, or outliers, and to determine their probable causes. The instruction will recommend how to identify obvious errors in the data, such as unrealistic capacity, and inconsistent volume measurements. This action will encourage analysts to identify data needs and requirements prior to collecting the data from various sources and prior to using collected data in the analysis.

Provide Detailed Data Requirement Policies

This action intends to achieve the following capability maturity improvement:

- From level 2: Some analysis projects adhere to data requirement settings, but the agency does not systematically set data requirements; the agency develops data mining and analysis methods for some functions and applications
- To level 3: The agency applies detailed data requirements, verification requirements, and data plan templates

This action involves the development of detailed policy that specifies the data quality and resolution for use in different levels of the analysis. As mentioned in the TSSM, potential data

quality measures are data accuracy, latency, availability, and depth of coverage (the resolution in space and time of the collected data items) (List et al., Forthcoming). FHWA's *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* (Wunderlich, Alexiadis, and Wang 2017) recommends focusing quality control procedures on the errors most likely to affect the model. However, such documents do not provide detailed requirements related to data quality. This action also involves provision of a template the analyst can use in developing the data plan. This action will ensure the analysts identify data needs and requirements prior to collecting the data from various sources, and prior to using collected data in the analysis. *Traffic Data Quality Measurement* (FHWA 2004) recommends the following measures for assessing data quality:

- **Data accuracy**—the degree of agreement between a data value or set of values and a source assumed to be correct
- **Completeness**—also referred to as availability, completeness measures how much data are available compared to how much data should be available; completeness is typically described in percentages or number of data values and can refer to both the temporal and spatial data availability
- **Validity**—reflects the percentage of data values that pass or fail data validity checks
- **Timeliness**—reflects the latency of data at the time required; since most analysts conduct simulation analysis in off-line environments, this measure is irrelevant to the discussion in this document
- **Coverage**—the degree to which a sample of the data accurately represents the whole population
- **Accessibility**—reflects the relative ease with which users can retrieve and manipulate the data

Specify Filtering Algorithms and Data Quality Requirements

This action intends to achieve the following capability maturity improvement:

- From level 3: The agency applies detailed data requirements, verification requirements, and data plan templates
- To level 4: The agency requires filtering algorithms and proof of data quality

This action suggests the analyst to submit proof of data quality, based on studies from prior efforts or the ongoing project. The agency also has tools to support the filtering and cleaning of data to meet specific data requirements of the traffic analysis effort, which account for the analysis type. It is important to understand data filtering methods, and possibly use them to determine the quality of data. Hadi et al. (2011), based on a review of literature, recommends a rule-based data filtering procedure that includes the following steps:

- Identification of duplicate data records
- A univariate test to check whether the values of individual traffic parameters exceed predefined minimum or maximum thresholds

- A multivariate test of data measurements to check for unreasonable combinations of traffic parameter values such as a combination of zero speed, zero occupancy, and non-zero volume values
- A temporal variability check to test for constant values of speed, volume, and occupancy for a long period of time, including all zeros, or illogical changes in values
- Multivariate tests for the average effective vehicle length and maximum density at the temporal aggregation level under consideration based on traffic flow theory equations
- A spatial check for the relative differences in traffic parameters between detectors at neighboring stations

This action ensures that analysts will obtain and filter the data in a way that achieves the level of data quality warranted by the conducted analysis. The provided data filtering and cleaning tools will provide significant support in this regard.

Use General Purpose Tools

This action intends to achieve the following capability maturity improvement:

- From level 1: No data analytics other than preparing data for inputs and use in calibration
- To level 2: Occasional use of visualization and analysis tools developed for other purposes

Data analytics and visualization using general purpose tools (and tools developed for purposes other than modeling) can help in calibrating simulation models, assessing system performance, and scoping traffic analysis efforts. This action involves sharing and providing access to data analytics and visualization tools developed for other purposes such as the TSMO program. For example, many agencies have implemented TSMO data archiving and analytics systems that could support traffic analysis. Such tools can provide significant support in assessing and visualizing system performance. The agency should provide instruction and training on the use of tools for this purpose.

Develop and Adopt Data Tools

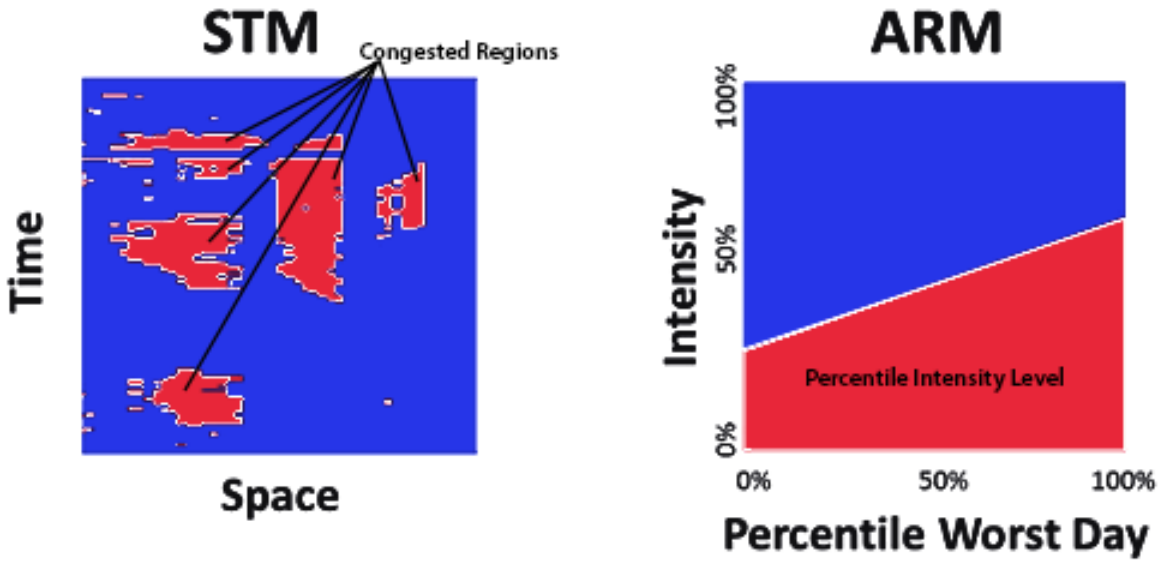
This action intends to achieve the following capability maturity improvement:

- From level 2: Occasional use of visualization and analysis tools developed for other purposes
- To level 3: Regular use of tools specifically developed to support the agency analysis process

Data analytics and visualization tools specifically developed or adopted for traffic analysis can provide much stronger support for calibrating simulation models, assessing system performance, and scoping traffic analysis efforts. This action involves developing or adopting the use of data processing, fusion, visualization, and analysis tools specifically created to support agency traffic

analysis processes. The agency specifies the tool utilization in its SOPs and provides training on the tools.

For example, one key aspect of traffic simulation is the modeling of bottleneck attributes. The analyst can use the congestion and bottleneck identification (CBI) tool[1] developed by FHWA (Hale et al., 2016, 2021) for assessing the bottleneck attributes. Analysts can apply the STM to compare real-world data to model outputs, such as speeds, travel time rate per mile, or density. Figure 13 illustrates the spatiotemporal traffic state matrix (STM) and annual reliability matrix (ARM) concepts.



Source: Hale et al. (2016).

Figure 13. Illustration. Spatiotemporal traffic state and annual reliability matrix concepts.

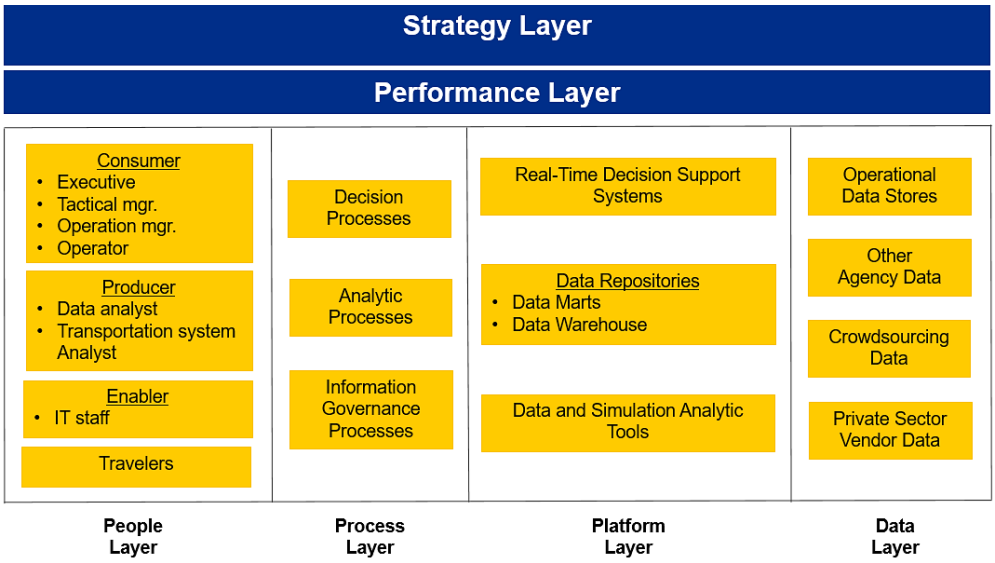
Use Integrated Modeling and Data Environment

This action intends to achieve the following capability maturity improvement:

- From level 3: Regular use of tools specifically developed to support the agency analysis process
- To level 4: Utilization of an integrated modeling and data environment

The action involves the use of an integrated modeling, data mining, and data analysis environment, which can support agency decisions. This subdimension will allow better support for decisionmaking. An integrated management support system can combine modeling, data analysis, and business intelligence to support agency decisions, as shown in figure 14.

[1] FHWA. n.d. "Congestion and Bottleneck Identification (CBI) Tool Software Download" (web page). https://highways.dot.gov/research/resources/software/congestion-bottleneck-identification-cbi-tool-software-download, last accessed December 13, 2022.



Source: FHWA.
mgr. = manager, IT = information technology.

Figure 14. Illustration. Proposed integrated management support system framework.

Use Data from Commonly Available Sources

This action intends to achieve the following capability maturity improvement:

- From level 1: Use of traditional data collection methods; no use of new sources of data to supplement analyses
- To level 2: Use of commonly available automated data sources

This action involves instruction on using popular automated data sources such as planning office permanent and portable counts, point detectors installed by TSMO programs, vehicle re-identification technologies (e.g., Wi-Fi readers), private sector travel time data, and private sector O-D data. In addition, this action may include entering into agreements with public agencies and data vendors for regionwide and statewide provision. This action will support analysts in getting required data for the analysis.

Use Data from New and Emerging Sources

This action intends to achieve the following capability maturity improvement:

- From level 2: Use of commonly available automated data sources
- To level 3: Use of data from new and emerging data sources

This action involves instruction on using additional data not commonly used for modeling, including high-resolution controller data, CAV data, vehicle trajectories, incident data, crash data, construction data, and weather data. In addition, this action will include entering into agreement with public agencies and contracts with data vendors for region-wide and statewide provision. This action will support analysts in getting required data for the analysis.

Fuse Data from Multiple Sources

This action intends to achieve the following capability maturity improvement:

- From level 3: Use of data from new and emerging data sources
- To level 4: Fuse data from existing and new data sources

The agency provides data from new and emerging data sources (e.g., vehicle trajectories, other high-resolution data) in the data archives, with data fusion modules, to support AMS projects. This action will support analysts in getting required data for the analysis.

Archive Data

This action intends to achieve the following capability maturity improvement:

- From level 1: No or very limited use of archived data
- To level 2: Use of State or regional data archives; ad-hoc download and use of databases

The action requires the analysis agencies to work with agencies that collect data from various sources. The action encourages and supports archiving of data in an agency-specific data mart, or in a regional or statewide data warehouse. The action ensures the data are not lost, and that they are available for analyses in various formats.

Provide Automated Data Access Tools

This action intends to achieve the following capability maturity improvement:

- From level 2: Use of regional data archives; ad-hoc download and use of databases
- To level 3: Analysis consideration in data archives; use of automated tools for data download

In this action, the analysis agencies work with the departments responsible for archiving the data in data marts or warehouses to ensure that data meet analysis requirements. The action ensures the provision of tools to assist the user in downloading data in various formats, aggregation levels, and spatial and temporal extents.

Implement Integrated Data Archiving and Analytic Environment

This action intends to achieve the following capability maturity improvement:

- From level 3: Analysis consideration in data archives; use of automated tools for data download
- To level 4: Integrated data archiving and analytic environment

This action involves developing an integrated data archiving and analytics environment. The environment allows enhanced reporting, querying, visualization, and analysis using data mining

and machine learning. The environment has specific functions to support the modeling environment. The environment allows analysts to generate standard and ad-hoc reports, and to visualize performance using various visualization techniques.

Initiate Data Governance

This action intends to achieve the following capability maturity improvement:

- From level 1: No or minimal data governance and management
- To level 2: Initiated data governance and management

This action initiates the discussion with partner agencies and IT departments to establish a data management and governance process. The process manages data collected for other transportation system planning and operations functions that can be used in transportation system analysis. The action also involves initiating the implementation of some concepts of data management and governance.

Establish Emerging Data Governance and Management

This action intends to achieve the following capability maturity improvement:

- From level 2: Initiated data governance and management
- To level 3: Emerging data governance and management

This action documents collaboration among partner agencies and IT departments to establish the data management and governance process. The process manages data collected for other transportation system planning and operations functions that can be used in transportation system analysis. Agency analysts and staff start to follow the data management and governance systems and policies. The documented data governance process includes the following:

- Establishing the mission and vision of data governance
- Defining and aligning roles and accountabilities of different players
- Identifying policies, standards, and compliance requirements
- Establishing control processes to detect and prevent harmful events
- Identifying the metrics of success of data governance
- Assigning responsibilities and accountabilities for compliance activities

Provide Integrated Data Governance and Management

This action intends to achieve the following capability maturity improvement:

- From level 3: Emerging data governance and management
- To level 4: Robust and integrated data governance and management

In this action, partner agencies apply documented data management and governance processes. Agencies assess and apply data governance metrics to improve the data governance process.

4.6 ANALYSIS PROCESS AND DOCUMENTATION

The following section provides a matrix of suggested actions to improve capability level (table 14), followed by a more detailed discussion of these suggested actions, for the analysis process and documentation dimension.

Table 14. Actions to advance to the next level for the analysis process and documentation dimension.

Subdimension	Level 1 to 2	Level 2 to 3	Level 3 to 4
Analysis approach	Build fundamental analysis capabilities	Build capability to incorporate additional tools, data sources, analysts, reviewers, and stakeholders	Build capability to apply multi-scenario, multimodal analysis, multiresolution analysis feedback loop, and integrated data and modeling analysis
Advanced and emerging strategies	Begin to analyze advanced and emerging strategies	Analyze some advanced and emerging technology applications using national best practices	Analyze advanced and emerging technology applications using approved procedures
Verification, calibration, and validation (VC&V)	Adopt standardized calibration methods	Adopt verification, calibration, and validation methods with analysis type-specific calibration targets	Adopt advanced verification, calibration, and validation techniques
Analysis reporting and documentation	Begin to document analysis activities and results	Adopt standardized documentation of analysis activities and results	Require documentation of analysis activities and results

Build Fundamental Analysis Capabilities

This action intends to achieve the following capability maturity improvement:

- From level 1: Simple analyses that take less than a week; facility-wide and network-wide analysis is not often used
- To level 2: Analyses that require multiple weeks due to additional effort on scoping, data preparation, data entry, calibration, output processing, or alternatives analysis

By developing the analysis capabilities listed in the level 2 bullet point, this action allows traffic analyses to be more robust and effective. Development and particularly the calibration of simulation models for larger sized networks (which may include both freeway and arterial facilities) can be challenging and require significantly greater expertise and resources. The action

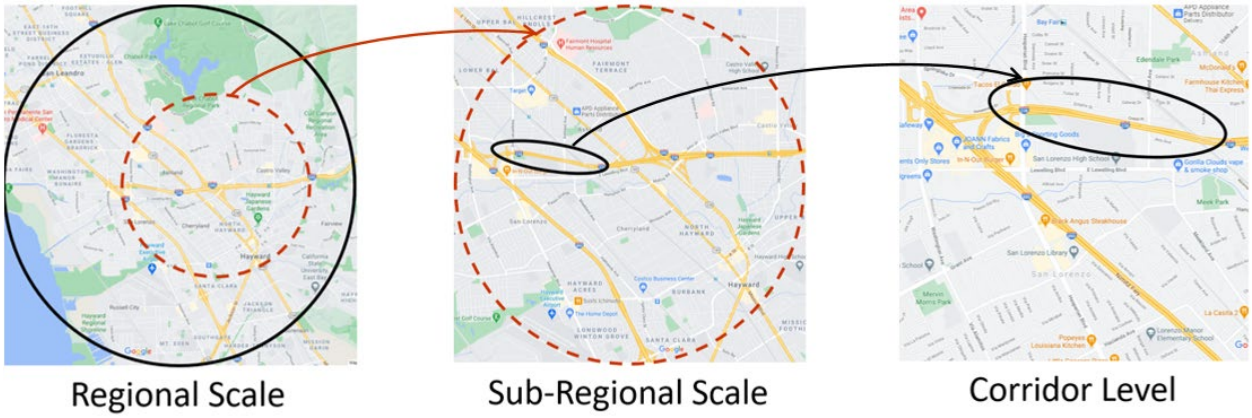
may involve learning advanced methods of microsimulation data entry, calibration and validation, and output processing. To support this, the agency provides analysis instruction that reflects State and national efforts. The agency may reference national sources, such as the HCM (TRB 2016), TSSM (List et al., Forthcoming),and *Traffic Analysis Toolbox* (FHWA 2004 – 2021)), or State sources such as those listed on the ITE SimCap homepage (Institute of Transportation Engineers 2021). The agency can also make use of in-house subject matter experts.

Build Capability to Incorporate Additional Tools, Data Sources, Analysts, Reviewers, and Stakeholders

This action intends to achieve the following capability maturity improvement:

- From level 2: Analyses that require multiple weeks due to additional effort on scoping, data preparation, data entry, calibration, output processing, or alternatives analysis
- To level 3: Analyses that require multiple months due to the steps mentioned in Level 2, plus integration of additional tools, data sources, analysts, reviewers, and stakeholders

The application of additional tools within a singular analysis (particularly at various analysis resolutions) can significantly improve the analysis results, depending on the project under consideration. DTA and MRM are effective for analyzing recurrent and non-recurrent congested conditions and associated mitigation strategies that impact strategic behaviors of travelers, such as route selection. Agencies may also need MRM to model advanced strategy applications, such as managed lanes, dynamic pricing, active traffic management, smart work zones, incident management, freight corridors, integrated corridor management, and other intelligent transportation systems and TSMO strategies. By developing the capability to apply DTA and MRM, this action allows agencies to model traffic networks more robustly. The agency might improve these capabilities by hiring staff who have DTA, MRM, and demand model experience, and identifying consultants who can accomplish this type of work. Alternatively, the agency might develop its existing staff. Although States do not have extensive instruction on DTA and MRM at the time of this writing, FHWA provides a DTA instruction document (Sloboden et al., 2012) and recently published MRM instruction (Hadi, Zhou, and Hale 2022). Figure 15 illustrates the integrated regional, subregional, and corridor analysis perspectives that MRM can provide.



Source: 2021 Google® Earth™ and Sloboden et al. (2012).
Notes: Annotations by FHWA to show regional-, subregional-, and corridor-level boundaries (see Acknowledgments).

Figure 15. Maps. Different multiresolution modeling analysis perspectives.

Similarly, agencies can build the capability to integrate additional data sources into the analysis, to gain further insights. Such additional data sources could include event/incident data, traffic performance data, traffic signal data, weather data, connected vehicle data, trajectory data, and transit data.

Build Capability to Apply Multi-Scenario, Multimodal Analysis, Multiresolution Analysis Feedback Loop, and Integrated Data and Modeling Analysis

This action intends to achieve the following capability maturity improvement:

- From level 3: Analyses that require multiple months due to the steps mentioned in Level 2, plus integration of additional tools, data sources, analysts, reviewers, and stakeholders
- To level 4: Capability to conduct multi-scenario modeling, multimodal analysis, travel time reliability analysis, and MRM with a feedback loop, when needed

This action allows agencies to perform more advanced analysis techniques if the analysis requirements identified in the scoping stage make such techniques necessary. The agency might improve these capabilities by hiring staff who have more expertise and identifying consultants who can accomplish the work. Alternatively, the agency might develop its existing staff. Note that analysts can apply many of the advanced techniques using deterministic analytical tools, as well as simulation models. For example, analysts can perform multi-scenario analysis considering traffic, incident, weather, and construction conditions regardless of the utilized tool type. Figure 16 illustrates an example of analyzing a small set of core scenarios, with each scenario involving specific levels of demand, weather, and incidents. *Traffic Analysis Toolbox Volume III* (Wunderlich, Vasudevan, and Wang 2019) provides a more rigorous methodology to conduct multi-scenario analysis.

Core Scenario	1	2	3	4	5	6	7	8	9	10	11	12
Demand	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Frequency	20%	40%	40%	20%	40%	40%	20%	40%	40%	20%	40%	40%
Weather	Ideal	Ideal	Ideal	Poor	Poor	Poor	Ideal	Ideal	Ideal	Poor	Poor	Poor
Frequency	70%	70%	70%	30%	30%	30%	70%	70%	70%	30%	30%	30%
Incidents	None	None	None	None	None	None	Yes	Yes	Yes	Yes	Yes	Yes
Frequency	70%	70%	70%	70%	70%	70%	30%	30%	30%	30%	30%	30%
Relative Frequency	9.8%	19.6%	19.6%	4.2%	8.4%	8.4%	4.2%	8.4%	8.4%	1.8%	3.6%	3.6%
Random # Seed Realizations	98	196	196	42	84	84	42	84	84	18	36	36

Source: FHWA.

Figure 16. Screenshot. Multi-scenario analysis.

Begin to Analyze Advanced and Emerging Strategies

This action intends to achieve the following capability maturity improvement:

- From level 1: No consideration of advanced and emerging strategies
- To level 2: Limited analysis of advanced and emerging strategies with limited consideration of the associated specific requirements

In this action, agency staff acquires the ability to model a limited number of advanced and emerging strategies. The analysts apply this capability in an ad-hoc fashion to satisfy specific project needs with limited consideration of the specific requirements to model these strategies.

Analyze Some Advanced and Emerging Technology Applications Using National Best Practices

This action intends to achieve the following capability maturity improvement:

- From level 2: Limited modeling advanced and emerging strategies with minor consideration of the associated specific requirements
- To level 3: Analyzing advanced and emerging technology applications utilizing national best practices in this modeling

In this action, agency staff acquires the ability to model multiple advanced and emerging technology applications. Rather than applying this capability in an ad-hoc fashion, the agency recognizes a need to develop a more robust capability in this area. As such, they seek out instruction, training, and example projects from transportation conferences, instruction documents, vendor resources, or other agencies.

Analyze Advanced and Emerging Technology Applications Using Approved Procedures

This action intends to achieve the following capability maturity improvement:

- From level 3: Analyzing advanced and emerging technology applications utilizing national best practices in this modeling

- To level 4: Analyzing advanced and emerging technology applications utilizing approved procedures

In this action, agency staff acquire the ability to frequently and efficiently model multiple advanced and emerging technology applications. The agency recognizes a need for robust capability in this area. After reviewing the available regional and national instruction and comparing it with its own project-driven experiences, the agency adopts approved procedures to model advanced and emerging technologies. The analysts work closely with planning and operations agencies for consistent modeling of advanced and emerging technology applications to support their decisionmaking process in a formal manner.

Adopt Standardized Calibration Methods

This action intends to achieve the following capability maturity improvement:

- From level 1: Calibration method and targets set at the project level. No validation procedure/sensitivity analysis is applied
- To level 2: Calibration methodology and targets set at the State and/or agency levels but no validation procedure is applied

In this action, the agency adopts specific calibration methods. As with the capability to model larger networks, the agency may have obtained these methods from national sources (e.g., HCM (TRB 2016), TSSM (List et al., Forthcoming), and *Traffic Analysis Toolbox* (FHWA 2004–2021)), State sources (e.g., listed on the ITE SimCap home page (Institute of Transportation Engineers 2021)), or in-house subject matter experts.

Adopt Verification, Calibration, and Validation Methods with Analysis Type-Specific Calibration Targets

This action intends to achieve the following capability maturity improvement:

- From level 2: Calibration methodology and targets set at the State and/or agency levels but no validation procedure is applied
- To level 3: Calibration based on analysis type-specific instruction, validation based on sensitivity analysis; analysts compare results from multiple tools to enhance the VC&V process

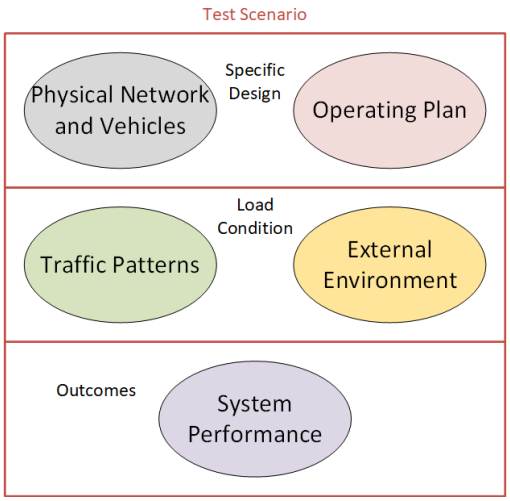
In this action, the agency requires analysts to test their calibrated models for other conditions not used in the calibration. If the validation results are unacceptable, the analysts perform additional calibration. The used calibration method is consistent with the spirit of the 2019 update in *Traffic Analysis Toolbox Volume III* (Wunderlich, Vasudevan, and Wang 2019) in that it considers the variation in traffic conditions when setting the calibration thresholds. The agency also requires the analyst to ensure DTA converge using documented convergence criteria.

Adopt Advanced Verification, Calibration, and Validation Techniques

This action intends to achieve the following capability maturity improvement:

- From level 3: Calibration based on analysis type-specific instruction, validation based on sensitivity analysis; analysts compare results from multiple tools to enhance the VC&V process
- To level 4: Analysts ensure that multi-tool analyses converge using documented criteria; the calibration process incorporates high-resolution data

In this action, the agency adopts advanced VC&V techniques. The calibration process incorporates high-resolution data (e.g., vehicle trajectories, probe data, ATSPM). In MRM projects, analysts pursue feedback and convergence between the different analysis resolutions. In multi-scenario projects, analysts apply VC&V techniques to all core scenarios. According to the TSSM (List et al., Forthcoming), each scenario should include unique traffic patterns (also known as load conditions) for a discrete number of specific designs and environmental conditions illustrated in figure 17. Analysts also automate the VC&V process to exploit high-resolution data sources (e.g., vehicle trajectories, ATSPM, probe data) that can improve model accuracy.



Source: FHWA.

Figure 17. Illustration. Components of a load condition.

Begin to Document Analysis Activities and Results

This action intends to achieve the following capability maturity improvement:

- From level 1: No or limited documentation requirements
- To level 2: Ad-hoc documentation of analysis activities and results

In this action, the agency requires documentation of analysis activities and results in sufficient levels of detail for the user of the analysis results. Analysts begin to document their analysis activities and results in a way that can help the users of the results and future analysts (who did not participate in the analysis). Agency reviewers review this documentation to get insight and request clarification in some areas. These requests lead to improved documentation resources in future efforts.

Adopt Standardized Documentation of Analysis Activities and Results

This action intends to achieve the following capability maturity improvement:

- From level 2: Ad-hoc documentation of analysis activities and results
- To level 3: Detailed documentation sufficient for reviewers

In this action, the agency recommends specific documentation standards for the analysis activities and results. These standards allow reviewers to understand all of the analysis steps in enough detail to enable a meaningful review.

Require Documentation of Analysis Activities and Results

This action intends to achieve the following capability maturity improvement:

- From level 3: Detailed documentation sufficient for reviewers
- To level 4: Detailed and consistent documentation sufficient for reviewers

In this action, the agency requires specific documentation standards for the analysis activities and results, and ensures that the requirements are met.

4.7 TOOL AVAILABILITY AND CAPABILITY

The following section provides a matrix of suggested actions for improve capability level (table 15), followed by a more detailed discussion of these suggested actions, for the tool availability and capability dimension.

Table 15. Actions to advance to the next level for the tool availability and capability dimension.

Subdimension	Level 1 to 2	Level 2 to 3	Level 3 to 4
Tool selection	Apply tool selection instruction	Apply agency-wide and analysis type-specific criteria	Develop direct experience with a wide variety of tools from various developers and vendors
Tool availability	Obtain access to alternative tools	Obtain access to a variety of tools for most analysis types	Obtain access to a wide variety of traffic analysis and data analytics tools from a wide variety of developers

Apply Tool Selection Instruction

This action intends to achieve the following capability maturity improvement:

- From level 1: Ad-hoc selection by the project public agency manager and the project consultant
- To level 2: Selection based on national, statewide, or agency-wide instruction; selection constrained by the available tools, knowledge, and experience

In this action, the agency adopts tool selection instruction for their analysts to follow. The agency may have obtained VC&V information from national sources (e.g., TSSM (List et al, Forthcoming), *Traffic Analysis Toolbox* (FHWA 2004–2021)), State sources (e.g., listed on the ITE SimCap home page (Institute of Transportation Engineers 2021)), or in-house subject matter experts. However, the agency does not consider using tools it has not yet procured and does not consider using tools its analysts have not used before.

Apply Agency-Wide and Analysis Type-Specific Criteria

This action intends to achieve the following capability maturity improvement:

- From level 2: Selection based on national, statewide, or agency-wide instruction; selection constrained by the available tools, knowledge, and experience
- To level 3: Tool selection based on detailed agency-wide criteria and analysis type-specific criteria; selection not constrained by the available tools, knowledge, and experience

In this action, the agency adopts detailed agency-wide tool selection criteria for the analysts to follow. The adopted criteria consider the scope and details of the project, such as signal control, managed lanes, and bus rapid transit. The agency can refine the criteria for the specific project under consideration to account for additional analysis needs. Hadi et al. (2016, 2017) is an example of an effort to develop more detailed criteria. On a case-by-case basis, the agency occasionally approves and possibly procures tools its analysts have not used before to satisfy the identified requirements.

Develop Direct Experience with a Wide Variety of Tools from Various Developers and Vendors

This action intends to achieve the following capability maturity improvement:

- From level 3: Tool selection based on detailed agency-wide criteria and project-specific criteria; selection not constrained by the available tools, knowledge, and experience
- To level 4: Agency staff have direct experience with using a wide variety of analysis tools from a wide variety of developers and vendors; agency staff are also familiar with the developers' future plans and directions for these tools

In this action, agency staff gain experience with using a wide variety of traffic analysis tools from a wide variety of developers and vendors. This experience gives them intimate knowledge of the advantages and disadvantages of these tools. The agency is thus in an excellent position to identify the right tool(s) for each job.

Obtain Access to Alternative Tools

This action intends to achieve the following capability maturity improvement:

- From level 1: Agency staff only have access to one preferred tool, or are uncomfortable with the thought of using other tools beyond their preferred tool
- To level 2: Agency staff only have access to a few preferred tools (possibly from the same vendor), or are uncomfortable with the thought of using other tools beyond their few preferred tools. Limited use of supplemental or add-on tools

In this action, the agency obtains access to multiple tools for the most common type of traffic analysis conducted by the agency (e.g., traffic impact analysis, traffic signal timing study, long-range forecasting, travel time reliability analysis, advanced and emerging strategies, geometric alternatives analysis). These tools provide different strengths and weaknesses for conducting the same type of analysis. Agency staff develop competency in each of these tools. In some projects, the agency may formally apply multiple tools for the same analysis in order to gain additional insight.

Obtain Access to a Variety of Tools for Most Analysis Types

This action intends to achieve the following capability maturity improvement:

- From level 2: Agency staff only have access to a few preferred tools (possibly from the same vendor), or are uncomfortable with the thought of using other tools beyond their few preferred tools; limited use of supplemental or add-on tools
- To level 3: Agency staff have access to a variety of tools for most types of traffic analysis; however, for certain types of traffic analysis, tool availability may be limited or sub-optimal; limited use of data analytics tools to assess and improve the quality of the data used for traffic analysis

In this action, the agency obtains access to multiple tools for most types of traffic analysis conducted by the agency. Agency staff develop competency in all of these tools.

Obtain Access to a Wide Variety of Traffic Analysis and Data Analytics Tools from a Wide Variety of Developers

This action intends to achieve the following capability maturity improvement:

- From level 3: Agency staff have access to a variety of tools for most types of traffic analysis; however, for certain types of traffic analysis, tool availability may be limited or sub-optimal; limited use of data analytics tools to assess and improve the quality of the data used for traffic analysis

- To level 4: Full access to a wide variety of traffic analysis tools and data analytics tools from a wide variety of developers and vendors

In this action, the agency gains full access to all of the traffic analysis tools used for all of the agency's typical analysis types. The agency is thus in an excellent position to use the right tool(s) for each job.

The agency also applies data science to enhance its traffic analysis capabilities. Analysts fuse multisource and multi-type data (e.g., event/incident, traffic congestion, traffic signal, weather, connected vehicle, trajectories, transit) to enhance their analysis process. The agency uses a decision support system that incorporates transportation system modeling and data analytics. The data fusion and decision support system use various data analytics techniques, including machine learning and artificial intelligence. An integrated management support system can combine modeling, data analysis, and business intelligence to support agency decisions (see figure 6 presented earlier). The framework lists the following types of analysis to support the decision process:

- Descriptive statistics
- Visualization
- Association and correlation rules
- Statistical regression models
- Decision trees and tree ensembles
- Bayesian classification
- Artificial neural network
- Support vector machine
- K-nearest neighbor
- Clustering
- AMS
- Return on investment
- Multicriteria decision analysis
- Post-deployment evaluations
- Expert rules and fuzzy logic

4.8 PERFORMANCE ESTIMATION AND MEASURES

The following section provides a matrix of suggested actions for improve capability level (table 16), followed by a more detailed discussion of these suggested actions, for the performance estimation and measures dimension.

Table 16. Actions to advance to the next level for the performance estimation and measures dimension.

Subdimension	Level 1 to 2	Level 2 to 3	Level 3 to 4
Performance measure selection	Provide general instruction	Implement selection based on predefined metrics	Implement selection as part of integrated decisionmaking process
Performance measure estimation	Consider measure estimation method	Specify definition and calculation methods	Use advanced performance measure estimation
Performance measure use	Use statistical and visualization techniques	Use extended analysis measures in multi-format	Use integrated business intelligence framework measures

Provide General Instruction

This action intends to achieve the following capability maturity improvement:

- From level 1: Ad-hoc performance measure selection
- To level 2: Use of general instruction and established practice for measure selection

This action involves providing recommendations about selecting performance measures in the AMS instruction produced by the agencies. The agency further pursues feedback from AMS projects regarding this instruction. *Scoping and Conducting Data-Driven 21st Century Transportation System Analyses* (Wunderlich, Alexiadis, and Wang 2017) and *Traffic Analysis Toolbox Volume VI* (Dowling 2007) can assist in this effort. The scoping guide highlights the need for analysis teams to define performance measures according to project objectives, mitigation strategies under consideration, stakeholders of the system, analysis scenarios, and operational conditions. The scoping guide recommends analysts report the selected measures by mode, facility, jurisdiction, and user type.

Implement Selection Based on Predefined Metrics

This action intends to achieve the following capability maturity improvement:

- From level 2: Use of general instruction and established practice for measure selection
- To level 3: Selection of measures based on predefined metrics identified for each type of project

This action involves identifying candidate measures for assessing the performance of specific agency functions (e.g., planning, interchange design, signal timing, TSMO). Analysts can update these measures based on project objectives. The measures reflect agency objectives and projects including those associated with mobility, reliability, safety, environmental impacts/sustainability, equity, resiliency, and so on.

Implement Selection as Part of Integrated Decisionmaking Process

This action intends to achieve the following capability maturity improvement:

- From level 3: Selection of measures based on predefined metrics identified for each type of project
- To level 4: Specified definitions and methods of calculation of performance measures

This action involves selecting measures based on an integrated business intelligence process. The process integrates the organizational, strategic, tactical, and operational objectives, measures, and decisionmaking processes.

Consider Measure Estimation Method

This action intends to achieve the following capability maturity improvement:

- From level 1: Use of performance measures produced as outputs of the analysis tools. Limited understanding of measure definitions and calculations in different tools
- To level 2: Recognition of differences in the measures estimated by different tools, and consideration of this in the analysis

Analysts may have limited understanding of measure definitions and calculations in different tools and procedures. This action involves explaining the differences and their implications in agency instruction and providing training and outreach. *Traffic Analysis Toolbox Volume VI* (Dowling 2007) provides a detailed discussion of the differences in performance measure estimation between different tools. Volume VI also discusses differences in calculation methods between the HCM procedures and simulation models, and between different simulation models.

Specify Definition and Calculation Methods

This action intends to achieve the following capability maturity improvement:

- From level 2: Recognition of differences in the measures estimated by different tools, and consideration of this in the analysis
- To level 3: Specified definitions and methods of calculation for performance measures

This action provides specific definitions and methods of calculation of performance measures (including nontraditional measures), for different uses of analysis, to support the decision processes. The measures may be the output of AMS tools. Alternatively, analysts may need to calculate these measures based on collected real-world data, AMS outputs, or vehicle trajectories from a simulation model. In addition to mobility measures, the measures can include nontraditional measures related to reliability, safety, emissions, equity, and other objectives. The HCM (TRB 2016) discusses the use of alternative tools, such as simulation, considering the differences in the calculation of measures between these tools and the HCM. Analysts can process the simulated vehicle trajectories to produce HCM-compliant measures, and can use tools in this processing.

Use Advanced Performance Measure Estimation

This action intends to achieve the following capability maturity improvement:

- From level 3: Specified definitions and methods of calculation for performance measures
- To level 4: Use of multimodal measures based on multiresolution, multi-scenario, and trajectory outputs

This action extends agency capabilities to specify calculation methods for multimodal measures (e.g., private cars, transit, commercial vehicles, and pedestrians/bicycles) and multi-user types (e.g., vehicles with different connectivity and automation). The specified methods will consider the use of multiresolution and multi-scenario analysis. The specified methods can incorporate trajectory outputs, if needed. In some cases, analysts use tool extensions and APIs to estimate the performance metrics.

Use Statistical and Visualization Techniques

This action intends to achieve the following capability maturity improvement:

- From level 1: Analysts report measures in a basic format without significant statistical analysis
- To level 2: Analysts use statistical analysis and visualization to compare alternatives

This action involves the use of hypothesis testing to compare alternatives, statistical analysis to compare alternatives, various techniques to visualize modeling results, and statistical equations to estimate the number of replications to account for stochasticity. *Traffic Analysis Toolbox Volume III* (Wunderlich, Vasudevan, and Wang 2019) and the TSSM (List et al., Forthcoming) provide useful information in this regard.

Use Extended Analysis Measures in Multi-Format

This action intends to achieve the following capability maturity improvement:

- From level 2: Analysts use statistical analysis and visualization to compare alternatives
- To level 3: Analysts use multi-format measures and additional analysis techniques

This action involves utilizing measures in different formats to satisfy the needs for different levels of decisionmakers. The action also includes the use of measures produced by extended analysis to improve the traffic analysis results, and to improve the confidence in these results. Recognizing that traffic analysis (particularly simulation analysis) can be costly and warrants a strong foundation, this action involves using preliminary analysis measures to determine the need for subsequent simulation analysis. The preliminary analysis can involve field data and/or the less costly HCM analysis. This action also involves using performance measures based on sensitivity analysis and considering uncertainty in the inputs or assumptions. The sensitivity analysis can first identify the inputs or assumptions with uncertainty, and then vary them to determine their impacts on the estimated measures.

Use Integrated Business Intelligence Framework Measures

This action intends to achieve the following capability maturity improvement:

- From level 3: Analysts use multi-format measures and additional analysis techniques
- To level 4: Analysts use measures in an integrated business intelligence framework

This action involves using the measures in an integrated business intelligence framework based on data and model analysis. The mapping of metrics at different levels to each other can help agencies identify cause-and-effect relationships between leading and lagging metrics and determine the contributions of lower metrics to upper metrics. Analysts can derive cause-and-effect relationships based on model and data analysis. Such use may also support setting measure targets, and monitoring if and why these targets are not met. The integrated decisionmaking process based on performance measures can justify changes in strategies, tactics, operation strategies, and associated investments. The integrated process derives cause-and-effect relationships and includes various agency actions.

This action also involves the use of modeling results combined with real-world and post-construction performance monitoring to trigger further analysis. The monitoring of system operations after the project improvement implementations will determine their effectiveness. Post-implementation monitoring will also help decision-makers assess the need for further analysis, and the potential need for further improvements. The results of such monitoring can also provide valuable information to future traffic analysis efforts.

CHAPTER 5. SUMMARY

The CMF presented in this document provides a systematic approach for transportation agencies to comprehensively assess their traffic analysis capabilities and identify practical steps for advancing to the next level of capability if desired. The framework recommends for agencies to perform the assessment for eight major dimensions of capability: *culture, workforce, collaboration, business process, supporting data, analysis process and documentation, tool availability and capability*. Four of the eight dimensions are business and relationship-oriented and address the agency's institutional support for traffic analysis. The other four dimensions are technical and traffic analysis-oriented and address the technical mechanics of traffic analysis. Overall, the developed framework includes 25 subdimensions over the eight dimensions.

Transportation agencies can use the CMF to identify their current capability maturity level for each of the subdimensions. The four levels are Performed, Initiated and Managed, Established, and Integrated and Optimized, indicating progression from basic analysis capability to advanced analysis capabilities. The agency can apply easy-to-use tables and multiple-choice questions (presented in chapter 3) for estimating capabilities across all eight dimensions. For identifying actions to reach the next level, the report (chapter 4) similarly provides easy-to-use tables that summarize the suggested actions, followed by a more verbose discussion of these same actions.

The CMF development effort anticipates that agencies will customize the criteria for indicating the various capability levels for each subdimension, and the actions to achieve the desired capability in each subdimension based on local needs and conditions. Before starting the assessment process, the transportation agency can identify the scope of the self-assessment, including the purpose, goals, and stakeholders to participate in the self-assessment process. Agencies can use a collaborative process when applying the CMF. This could involve a stakeholder workshop to first determine the agency's capability level using the approaches described in this document. The stakeholders could then identify, filter, and compile a set of actions appropriate to the region or agency. Follow-up meetings can then identify how to implement and review the implementations of the actions.

The agency can interpret the results of the self-assessment and use the results in developing an action plan to improve its analysis capabilities. The action plan will identify the approaches and required resources to advance their analysis capabilities. Agencies should update this action plan as they implement various actions and assess their effectiveness while considering lessons learned and newly identified needs for additional capabilities. These incremental action steps can help agencies advance their traffic analysis capabilities to better support the evaluation of transportation improvements, including traffic management and operation strategies for freeways, arterials, and corridors.

ACKNOWLEDGMENTS

For figure 15, the original map is the copyright property of Google® Earth™ and can be accessed from https://www.google.com/earth. The map overlays showing regional-, subregional-, and corridor-level boundaries were developed as a part of this research project. The research team adapted figure 15 from Sloboden et al., 2012 (see References section).

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