Texas Department of Transportation

TxDOT Statewide TSMO Benefit-Cost Analysis

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Version 2.0

Prepared By

AECOM Imagine it. Delivered.

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Date	Version	Description
6-9-20	1.0	Traffic Operations Safety Division Review (Prepared by AECOM)
2-16-21	2.0	Addresses AECOM Review Comments

List of Acronyms

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
AI	Artificial Intelligence
AMS	Analysis, Modeling, and Simulation
ATMS	Advanced Traffic Management System
ATSPM	Automated Traffic Signal Performance Measures
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
CAT	Cooperative Automated Transportation
CCTV	Closed Circuit Television
CMM	Capability Maturity Model
CO	Carbon Monoxide
CRCS	Connected Roadway Classification System
CRIS	Crash Records Information System
CV	Connected Vehicle
DOT	Department of Transportation
DMS	Dynamic Message Sign
EOC	Emergency Operations Center
FHWA	Federal Highway Administration
H/W	Hardware
HOT	High Occupancy Toll
ICM	Integrated Corridor Management
IT	Information Technology
ITD	Information Technology Division
ITS	Intelligent Transportation Systems
LAN	Local Area Network
LCS	Lane Control Sign
LMS	Learning Management System

Acronym	Definition
MPO	Metropolitan Planning Organization
NOx	Nitrous Oxides
O&M	Operations and Maintenance
PBC TED	Palm Beach County Traffic Engineering Department
PM	Particulate Matter
RIMS	Regional Incident Management System
S/W	Software
SHRP	Strategic Highway Research Program
SME	Subject Matter Expert
SOP	Standard Operating Procedures
TIM	Traffic Incident Management
TIP	Transportation Improvement Program
TMC	Transportation Management Center
TIM-BC	Traffic Incident Management Benefit-Cost Tool
TMS	Traffic Management System
TOPS-BC	Tool for Operations Benefit-Cost Analysis
TRF	Traffic Safety Division (Central Office)
TSMO	Transportation Systems Management & Operations
TxDOT	Texas Department of Transportation
USDOT	United States Department of Transportation
VMS	Variable Message Sign
VOC	Volatile Organic Compound

1. Introduction

Benefit-Cost Analysis (BCA) plays an important role in the TSMO decision-making process to help planners, engineers and operations managers determine:

- Whether or not a TSMO strategy or project should be implemented.
- When a TSMO strategy or project should be implemented.
- Which among competing strategies, alternatives and projects should be funded given a limited budget.
- Whether or not the TSMO strategy or project was cost effective after being implemented.

A BCA can provide valuable input to the many different phases of the project development process. During the planning phase, it can be applied to basic cost and performance data to screen potential alternatives, and assisting in the development of program budgets and areas of program emphasis. During the operations phase, the BCA may be used to drive continuous improvement in addressing TSMO goals (e.g., incident clearance, safety, mobility, reliability) as well as support TSMO funding requests by demonstrating benefits to the participating agencies (e.g., operational integration and efficiency) and the public (e.g., reduced delays, crash reduction).

The 2020 Statewide TSMO Strategic Plan Update provides high level strategies, presented in Table 1 below, to improve the capability maturity of the TxDOT organization in alignment with TSMO goals.

Table 1: TSMO Strategies

Strategies
Business Processes
1. Develop and Apply Methodology to Allocate ITS/Signals O&M Funding to Align with TSMO Goals
2. Develop Statewide Standard Operating Procedures to Improve Operational Interoperability
3. Improve Procurement Processes to Support TSMO Program Objectives
4. Develop Emergency Response Plan to Improve Preparedness, Response and Recovery
5. Conduct Cybersecurity Vulnerability Analyses of IT Networks to Improve Resiliency
Systems and Technology
6. Conduct Connected Roadway Classification System (CRSC) Analysis to Prepare for CAT
7. Develop AI/Machine Learning Applications that Address Common Operational Scenarios
8. Increase ITS Systems Support by TRF to the Districts to Improve Asset Uptime
9. Develop and Implement Integrated Corridor Management along Applicable Strategic Corridors
10. Develop Enhanced Traffic Signal System Implementation Plans
11. Implement Lonestar™ Enhancements
Performance Measures
12. Implement Performance Dashboards for Safety and Travel Reliability During Construction

13. Apply Performance Measures to all Applicable Phases of Project's Life Cycle (Planning-Operations)	
Organization and Workforce	
14. Develop a Succession Plan for Essential Staff to Provide Continuity of Operations	
15. Develop and Maintain a Learning Management System (LMS)	
Culture	
16. Apply Gamification Strategies as an Incentive to Continuously Improve Operational Performance	
17. Realize the Full Potential of TxDOT's ITS Infrastructure During Pandemic Events	
Collaboration	
18. Support Rural District Operations that have Limited Resources to Support TSMO Goals	
19. Strengthen TIM Teams Collaboration with Stakeholders to Safely Reduce Incident Clearance Times	
20. Develop Special Event Checklist to Apply TSMO Strategies	

BCA best practices require the analyst to include non-quantifiable impacts in a qualitative discussion. BCA should be comprehensive in addressing both quantitative and qualitative benefits and costs. Therefore, this technical memorandum is structured as follows (Figure 1):

- **Strategic Plan** – provides 20 strategies (Table 1) that address the needs to improve capability maturity in the following six CMM dimensions: business processes; systems and technology; performance measures; organization and workforce; culture; and collaboration.

- **Benefit-Cost Analysis (Qualitative Method)** – provides a high-level assessment of the benefits, costs and benefit-cost ratio (BCR) in qualitative terms. While the initial qualitative assessment presented in this technical memorandum reflects the opinion of AECOM, it may be used as a starting point in applying the Delphi Method in building consensus among Subject Matter Experts (SME) representing the TxDOT divisions and districts.

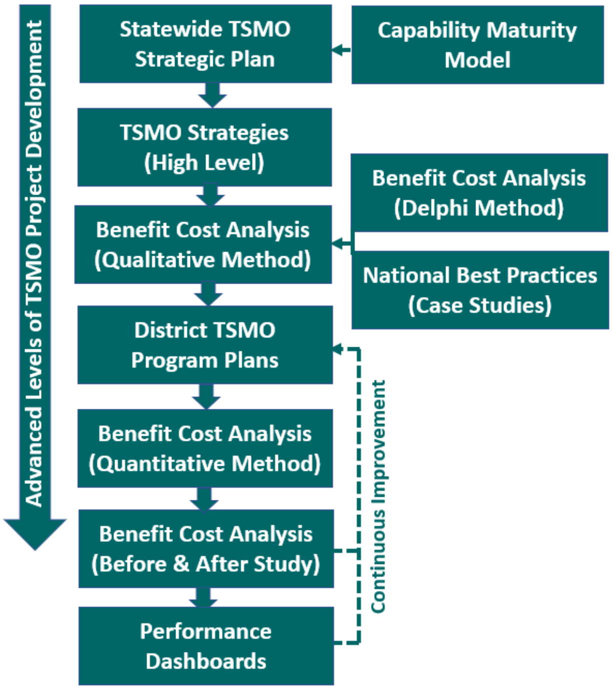


Figure 1: Benefit Cost Analysis Process

- **National Best Practices (Case Studies)** – provides best practices and case studies in other states to use as a benchmark for anticipated benefits and costs of selected TSMO strategies.

- **District TSMO Program Plans** – provides tactical plans for each of TxDOT's 25 districts, based on their specific needs, consistent with the 2020 Statewide TSMO Strategic Plan Update as an overarching framework.

- **Benefit-Cost Analysis (Quantitative Method)** – provides a more detailed methodology, and supporting software tools, to estimate quantitative benefits, costs and BCR for TSMO tactical plans during more advanced stages of project development.
- **Benefit-Cost Analysis (Before & After Study)** – provides an assessment on how well the TSMO strategy is performing after it is implemented. This assessment provides an opportunity to modify, expand or delete the strategy based on its performance.
- **Performance Dashboards** – Subsequent to a BCA Before & After Study, performance measures should be monitored on a regular basis comparing actual versus target metrics. This would provide a basis for further refinement of TSMO strategies, if necessary.

2. Benefit Cost Analysis (Qualitative Method)

TSMO strategies presented in the 2020 Statewide TSMO Strategic Plan are high-level and aligned with the six dimensions of the CMM framework. As such, the benefits, costs and BCRs are expressed in qualitative terms. In general, there is value realized simply as a result of going through the process of developing the Statewide TSMO Strategic Plan and District TSMO Program Plans. These positive outcomes include the following:

- **Business Processes** – TSMO provides an opportunity to think outside the box in conducting a high-level assessment of existing business processes. Through one-on-one meetings with TxDOT Leadership, and CMM workshops conducted with TxDOT division management, areas needing improvement are identified allowing business processes to become more structured, integrated and optimized. This will result in a more cost-effective way of doing business and maximizing resources in using available funds.
- **Systems and Technology** – Since the 1990s, TxDOT has made significant investments in building, operating and maintaining the Intelligent Transportation Systems (ITS) infrastructure throughout the state to improve traffic safety and mobility. These investments include development of regional Transportation Management Centers (TMC), the Lonestar™ Advanced Traffic Management System (ATMS) software, ITS field devices (e.g., CCTV cameras, dynamic message signs, vehicle detectors) as well as communications systems. These system improvements have provided a strong return on investment. As the pace of emerging technologies has accelerated in recent years, it is essential to conduct due diligence to ensure that newer versions of existing systems and new technologies provide a net gain in terms of capabilities and cost effectiveness or whether a swap in technologies is needed to keep abreast of current best practices. This will result in managing life-cycle costs of systems more cost effectively.
- **Performance Measurement** – Performance measures are used to evaluate the effectiveness of TSMO strategies and whether changes are needed to achieve safety and mobility goals. They are needed to justify TSMO programs and making the business case for investment. By defining measures, targets, data acquisition, analytics, reporting and utilization it enables TxDOT management and operations staff to determine how well the transportation system is being managed. This is anticipated to result in continuous operational improvements at the state and district levels.
- **Organization and Workforce** – Technically qualified staff and an organizational structure that unites TSMO activities into an integrated project delivery approach are key in supporting effective TSMO solutions. Through training, identifying TSMO responsibilities and building relationships across teams, TSMO functions will be engrained in TxDOT's day-to-day work efforts. By conducting an objective assessment of TxDOT's organizational structure, staff development, recruitment and retention methods it will enable TxDOT to be organized and staffed to carry out TSMO objectives and responsibilities. This will result in a resilient workforce to address today's and tomorrow's needs in achieving a higher level of capability maturity.
- **Culture** – The culture of an organization represents the values and beliefs that lead to certain decisions being made. Through a business case or outreach opportunities, TSMO messaging can be communicated to others inside and outside of TxDOT to gain support. With respect to TSMO, this level of understanding, leadership and outreach will demonstrate the value of TSMO and how well it is understood by TxDOT's divisions and districts.

- **Collaboration** – The effectiveness of TSMO activities depends on the ability of divisions, districts, partner agencies and other stakeholders to work together. Taking advantage of opportunities to build internal and external relationships will help with communication and overcoming challenges in the future. Throughout Texas, interagency partnerships are in place, but more organization is needed to collaborate, engage stakeholders and develop formal agreements. This will result in stronger relationships and partnering among levels of government and with public safety agencies, local governments, metropolitan planning organizations (MPO) and the private sector to achieve a higher level of capability maturity in managing the transportation system more effectively and efficiently.

A qualitative BCA was conducted identifying the benefits and costs for each strategy recommended as part of the 2020 Statewide TSMO Strategic Plan (Strategic Plan). In terms of benefits, it is assumed that the qualitative rating is a function of the number of people directly or indirectly affected and magnitude of impact of the change. Costs are categorized as "high" (more than $5 million), "medium" (between $1 and $5 million), and "low" (less than $1 million). "Soft" costs are labor costs by either TxDOT staff or consultants to develop and implement the strategy while "hard" costs include TSMO deployment costs as well as recurring operations and maintenance (O&M) expenses. Qualitative BCR ratings (i.e., high, medium, low) are defined in Table 2 by comparing benefits and costs while Table 3 provides a qualitative assessment of the benefits and costs for each strategy recommended as part of the Strategic Plan.

Table 2: Qualitative BCR Rating

	High Benefits	Medium Benefits	Low Benefits
High Costs (> $5 million)	Medium	Medium	Low
Medium Costs ($1 - 5 million)	High	Medium	Low
Low Costs (< $1 million)	High	Medium	Medium

Table 3: TSMO Strategies – Benefit Cost Analyses (Qualitative)

TSMO Strategy	Benefits	Costs	BCR
Business Processes			
Develop and Apply Methodology to Allocate ITS/Signals O&M Funding to Align with TSMO Goals	Reliable O&M funding stream to leverage ITS/Signal deployment investments. Ability to program life cycle and replacement costs in a more rational manner.	Life cycle costs to provide reliable ITS/Signals infrastructure, operations and maintenance to support TSMO Program Plan goals.	High
Develop Statewide Standard Operating Procedures to Improve Operational Interoperability	Statewide consistency in providing operations. Interoperability to provide fail-over operations and share	Soft costs in developing SOPs and training materials. Hard costs in deploying the communications	Medium

TSMO Strategy	Benefits	Costs	BCR
	functions during emergencies and for cross-district events.	infrastructure to support interoperability.	
Improve Procurement Processes to Support TSMO Program Objectives	Procurements that are sensitive to users' needs at the district level. Reliable tested products having a proven track record.	Soft costs in assessing current procurement processes and implementing recommendations.	Low
Develop Emergency Response Plan to Improve Preparedness, Response and Recovery	Consistent approach to emergency evacuation, response and recovery. RIMS application can enhance real time situational awareness of responder resources and TSMO assets.	Soft costs to develop a Comprehensive Emergency Management Plan. Expanding the coverage of RIMS to monitor responder resources and TSMO assets beyond the Houston District.	High
Conduct Cybersecurity Vulnerability Analyses of IT Networks to Improve Resiliency	Ensures business continuity through improved resilience, preparedness, detection and response for an IT breach. Budget justification to harden IT security and resilience.	Soft costs in conducting cybersecurity vulnerability analyses on a regular basis. Hard costs to protect assets, systems and networks from potential vulnerabilities.	High
Systems and Technology			
Conduct Connected Roadway Classification System (CRCS) Analysis to Prepare for Cooperative Automated Transportation (CAT)	Provides a rational approach to identify gaps in applying CAT systems within strategic corridors. Enables strategic corridors to be better prepared for incrementally accommodating CAT technologies.	Soft costs to conduct CRCS analyses in selected corridors. Hard costs in providing the field devices and other supporting systems to improve CAT readiness.	Low
Develop AI/Machine Learning Applications that Address Common Operational Scenarios	Automated (or semi-automated) tools to support data driven decisions and solutions. Reduced manual processes resulting in more efficiency and higher data quality.	Soft costs in applying the systems engineering process to develop AI tools. Soft costs in developing AI pilot projects, then expand to broader applications integrating with Lonestar™.	Medium

TSMO Strategy	Benefits	Costs	BCR
Increase ITS Systems Support by TRF to the Districts to Improve Asset Uptime	Higher level of support in addressing systems and technology procurement and acceptance testing. Provides technical expertise for emerging technologies.	Labor costs for SMEs as either new hires or consultants to support the districts in providing a higher level of technical support.	Medium
Develop and Implement Integrated Corridor Management along Applicable Strategic Corridors	Improves trip reliability during freeway closures via diversion routes via real time signal timing adjustments. Improves people throughput capacity for multimodal applications.	Soft costs in applying the systems engineering process to develop requirements, SOPs, training materials and interagency agreements. Hard costs in developing software and installing supporting systems.	Medium
Develop Enhanced Traffic Signal System Implementation Plans	Reduced delays, crashes and queueing at signals along TxDOT state roadways. Reduced asset downtime due to incidents, malfunctions and end-of-life equipment.	Soft costs to prepare Signal System Implementation Plans at state and district levels. Hard costs in implementing the plans (i.e., hardware, software, communications).	High
Implement Lonestar™ Enhancements	More robust ATMS software to meet growing TSMO needs. More user-friendly applications to optimize system usage.	Soft costs to implement and integrate Lonestar™ enhancements at TMCs. Procurement costs of new software modules and hardware, if needed.	Medium
Performance Measures			
Implement Performance Dashboards for Safety and Travel Reliability During Construction	Improve trip reliability of active work zones by monitoring "actual vs. expected" travel times. Reduce crash potential for both primary and secondary incidents through work zones.	Systems integration costs to develop real time (or predictive) dashboards and conduct pilot test at a TMC. Systems integration costs to roll out operational dashboards to other TMCs.	Medium

TSMO Strategy	Benefits	Costs	BCR
Apply Performance Measures to all Applicable Phases of Project's Life Cycle (Planning-Operations)	Enables continuous improvement in all phases of a project's life cycle. Supports TIM After Action Reviews improving incident detection, verification, response & clearance times.	Soft costs in defining performance measures for each phase of a project's life cycle. Systems integration costs to develop performance dashboards.	Medium
Organization and Workforce			
Develop a Succession Plan for Essential Staff to Provide Continuity of Operations	Provides the required training to support TSMO goals and develop applicable skill sets. Offers a career development path leading to higher levels of staff retention.	Soft costs in identifying specific training needs. Soft costs in developing and implementing training and certification programs.	Medium
Develop and Maintain a Learning Management System (LMS)	Offers training to staff and stakeholders anytime, anywhere. Enables training for new employees; provides recurrent skills training as well as training to support career development.	Procurement costs for a vendor to install and maintain the LMS. Recurring costs to populate and update the LMS with appropriate training, testing and certification materials.	Medium
Culture			
Apply Gamification Strategies as an Incentive to Continuously Improve Operational Performance	Instills competition among staff to perform better than performance targets. Highlights TSMO successes to executive management.	Systems integration costs to develop software tools to automate gaming functions for a pilot application. Systems integration costs to roll out gamification for other functions, divisions and districts.	Medium
Realize the Full Potential of TxDOT's ITS Infrastructure During Pandemic Events	Provides a broader and more robust role for TSMO and the ITS infrastructure to support other functions during pandemic events (COVID-19).	Systems integration costs to expand TMC functions to address other functions.	High

TSMO Strategy	Benefits	Costs	BCR
		Hardware and communications costs to support required functions.	
Collaboration			
Support Rural District Operations that have Limited Resources to Support TSMO Goals	Sharing staff, systems and technologies to address lack of resources within individual rural districts. Cost sharing among bordering districts results in economy of scale.	Soft costs to prepare checklists to offer guidance in requesting ITS as part of roadway projects. Soft costs to provide TIM training. Soft costs to develop partnering agreements among districts to share maintenance technicians.	High
Strengthen TIM Teams Collaboration with Stakeholders to Safely Reduce Incident Clearance Times	Improves communications and incident notifications with stakeholders. Strengthens agency partnerships to improve incident clearance times.	Soft costs to develop a TIM strategic plan to address TIM Self-Assessment deficiencies. Soft costs to develop and execute interagency agreements.	High
Develop Special Event Checklist to Apply TSMO Strategies	Provides a structured approach to special event planning including traffic management, parking, roadblocks, security and pedestrian traffic.	Soft costs in preparing pre-approved traffic management plans, SOPs, training and checklists.	Medium

Delphi Method

Benefits and costs for each TSMO strategy can be qualitatively rated using the Delphi Method by interviewing SMEs. The steps for applying the Delphi Method are:

- **Step 1** – Selection of SMEs representing the TxDOT divisions and districts most relevant to the TSMO program goals. The SME participants would come together as a group or meet in a virtual workshop.
- **Step 2** – Initial presentation of background information so that everyone starts with the same understanding of the strategy and can ask questions. The initial presentation of benefits, costs and timeframe for each TSMO strategy will be discussed.
- **Step 3** – Discussion of benefits, costs and BCR ratings as an iterative process to build consensus on the results. If consensus cannot achieved, then identify the reasons why and assign to an independent review committee or assign the owner of the TSMO strategy the final decision authority.
- **Step 4** – After all rounds of SME discussions have been completed, modify the initial qualitative rating of benefits, costs and BCRs for each TSMO strategy presented in Table 3.

At the conclusion in applying the Delphi Method, there may still be a significant disparity of ratings. This may be caused by several factors including providing opinions from the perspective of metro, urban and rural districts. In such cases, a subsequent risk analysis may be performed where the root causes of the disparity are identified and arbitrated by an independent technical review team. For example, while an Integrated Corridor Management TSMO strategy may be rated high by metro and urban districts it may be rated low by rural districts. In such cases, the ratings may be disaggregated to better reflect the geography and travel characteristics of the district. Another example may be the inability of a rural district to support a TSMO strategy by itself. However, when inter-dependencies are considered with neighboring districts, the rating may improve.

The duration of this approach, including the number of iterations and number of SMEs comprising the panel, is dependent on available resources. Table 4 lists some general advantages and disadvantages of the Delphi Method.

Table 4: Delphi Method Advantages and Disadvantages

Advantages	Disadvantages
Attempts to build consensus among differing opinions.	Ratings are still assigned by a select group and not necessarily representative of all TxDOT divisions and districts.
Mitigates bias in rating TSMO strategies.	Technique can be time-consuming and considered redundant with CMM surveys.
Allows participants to be anonymous or allows for interaction that can be informative and capture issues and opportunities not yet identified.	
Well selected SME panel can provide broad analytical perspectives on impacts, including new benefits and costs not yet identified.	
Flexibility and applicability to various issues.	

3. Benefit Cost Analysis (Case Studies)

While the data to support a quantitative BCA is not typically available at the Strategic Plan level, case studies of TSMO implementations in other states may provide a benchmark estimate of BCRs. The following TSMO strategies are examples of quantitative BCAs that have been conducted in other states as well as Texas.

Strategy No. 9: Develop and Implement Integrated Corridor Management along Applicable Strategic Corridors

BCAs have been conducted on several Integrated Corridor Management (ICM) programs in many cities throughout the United States including Dallas, San Diego, Minneapolis and San Francisco. Transportation researchers have used Analysis, Modeling and Simulation (AMS) methodologies to estimate the impacts of proposed ICM solutions. BCRs range from 7 to 25 over a ten-year period as shown in Table 5 below. These are high values of BCRs as compared to many other types of transportation investments (e.g., roadway and transit improvements).

Table 5: Benefit Cost Analysis of Integrated Corridor Management (ICM)

Evaluation Measures	San Diego	Dallas	Minneapolis	San Francisco
Annual Travel Time Savings (Person-Hours)	246,000	740,000	132,000	1.2 million to 4.6 million
Improvement in Travel Time Reliability	10.6%	3%	4.4%	-
Gallons of Fuel Saved Annually	323,000	981,000	17,600	3.1 million to 4.6 million
Tons of Mobile Emissions Saved Annually	3,100	9,400	175	20,400 to 20,800
10-Year Net Benefit*	$104 million	$264 million	$82 million	$570 million
10-Year Cost	$12 million	$14 million	$4 million	$75 million
Benefit-Cost Ratio	10	20	22	7 to 25

The above ICM programs are multimodal in scope and include significant investments in software development as part of decision support systems. Future ICM programs along other strategic corridors within Texas may begin with a more modest scope focusing on freeway-arterial operational integration, then evolve to encompass additional modes and complexity in the future. As additional ICM corridors are implemented and connected additional systemwide benefits (e.g., travel time reliability, people throughput) are anticipated. Furthermore, additional ICM implementations may make earlier ICM implementations more effective providing additional benefits.

Strategy No. 10: Develop Enhanced Traffic Signal System Implementation Plans

BCAs have been conducted on various traffic signal system programs throughout the United States. These programs include applying active arterial management for systems located in Colorado and Florida as well as traffic adaptive systems in other locations.

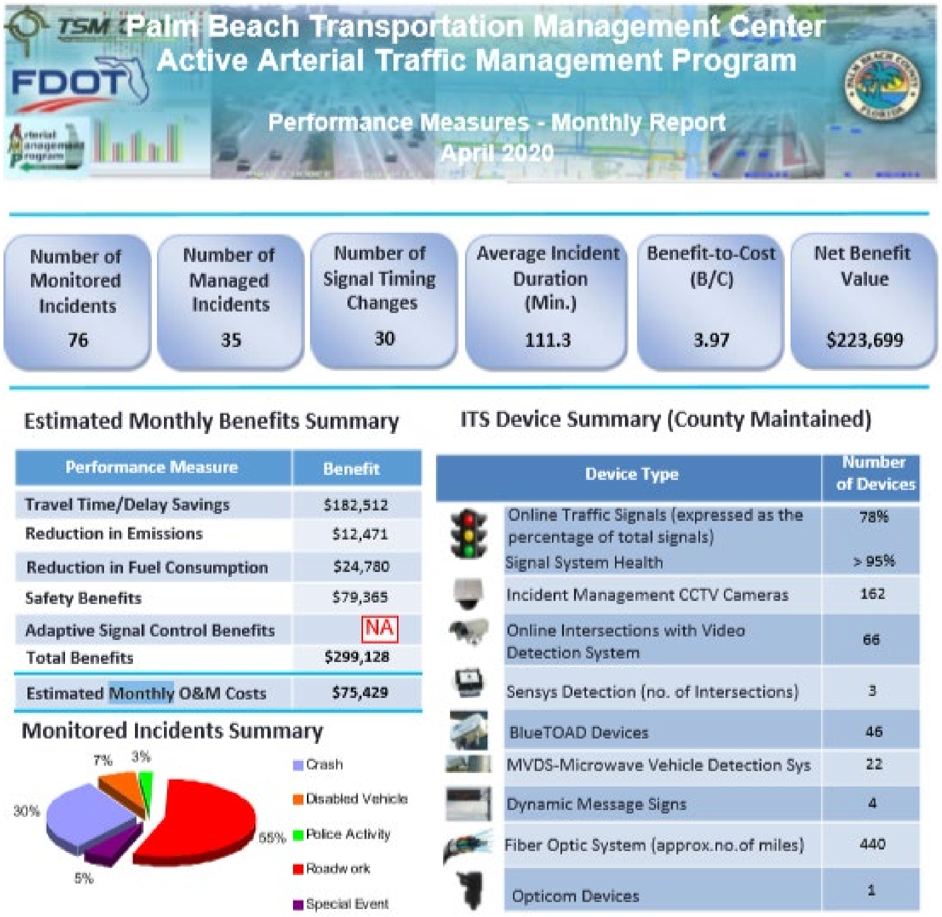
Denver, Colorado

Since 1989, the Denver Regional Council of Government's Traffic Operations Program has partnered with the Colorado DOT and local governments to coordinate traffic signals along major roadways within the region. State DOTs, MPOs, and other local transportation agencies can use BCAs to determine whether to implement traffic signal timing programs and projects. BCAs can inform decision makers as to the best locations for improving signal timing and the most cost-effective alternatives to employ. Many pre-developed tools exist to help practitioners conduct BCAs. The TOPS-BC spreadsheet tool, developed by FHWA, is one option and was applied to the Denver signal system program and estimated that the BCR exceeded seven.

Palm Beach County, Florida

The Florida DOT (District Four) collaborated with the Palm Beach County Traffic Engineering Department (PBC TED) in developing a "Living Lab" pilot project in 2012 to actively monitor, manage and improve arterial operations along three major east-west corridors. The project costs included equipment and devices installed within the study area along with O&M costs. Several cost items were also provided by PBC TED such as TMC operators, incident management software, licensing for the signal system software and an INRIX® data subscription. These costs were considered basic infrastructure costs because they are needed to operate the countywide traffic signal system regardless of the Living Lab project. Using the TOPS-BC spreadsheet tool, quantified costs and benefits were estimated and monetized for travel time savings, crash reductions and energy savings. The resulting BCR for this case study is ten.

The Florida DOT and PBC TED continue to provide active arterial traffic management along the countywide system encompassing over 1,100 traffic signals. Performance measurement reports are produced on a monthly basis and includes the BCR as shown in Figure 2. For the month of April 2020, the BCR was nearly 4.0.



Palm Beach Transportation Management Center
Active Arterial Traffic Management Program
Performance Measures - Monthly Report
April 2020

Number of Monitored Incidents	Number of Managed Incidents	Number of Signal Timing Changes	Average Incident Duration (Min.)	Benefit-to-Cost (B/C)	Net Benefit Value
76	35	30	111.3	3.97	$223,699

Estimated Monthly Benefits Summary

Performance Measure	Benefit
Travel Time/Delay Savings	$182,512
Reduction in Emissions	$12,471
Reduction in Fuel Consumption	$24,780
Safety Benefits	$79,365
Adaptive Signal Control Benefits	NA
Total Benefits	$299,128
Estimated Monthly O&M Costs	$75,429

Monitored Incidents Summary

ITS Device Summary (County Maintained)

Device Type	Number of Devices
Online Traffic Signals (expressed as the percentage of total signals)	78%
Signal System Health	> 95%
Incident Management CCTV Cameras	162
Online Intersections with Video Detection System	66
Sensys Detection (no. of Intersections)	3
BlueTOAD Devices	46
MVDS-Microwave Vehicle Detection Sys	22
Dynamic Message Signs	4
Fiber Optic System (approx.no.of miles)	440
Opticom Devices	1

Figure 2: Palm Beach County Active Arterial Traffic Management Program

Adaptive Traffic Signal Control

Adaptive traffic signal control systems coordinate signals across a network, adjusting the lengths of signal phases based on prevailing traffic conditions. This technology uses real-time data collected by system detectors to optimize signal timing for each intersection within the corridor. The use of real-time data means that signal timing along the corridor changes to accommodate traffic patterns throughout the day.

A State DOT commissioned the evaluation of an adaptive traffic signal control system on a principal arterial. The goal of the traffic signal control project was to reduce congestion, smooth traffic flows, improve travel times, maximize the benefits of signal timing and potentially reduce crashes.

Prior to and after the deployment, the study collected data on roadway performance. The BCA revealed improvements in terms of travel time, fuel consumption and side street delay. The BCR for this project is between five and six.

Strategy No. 12: Implement Performance Dashboards for Safety and Travel Reliability During Construction

A "smart work zone system" is the application of computers, communications and sensor technology to improve traffic and worker safety as well as trip reliability through active construction and roadway maintenance sites. To reduce crashes and fatalities within work zones, AECOM prepared a statewide report for TxDOT in 2018 assessing Smart Work Zone ITS including multiple site deployments/coordination, a go/no go process, a queue length estimator and a system costs evaluator along with a Concept of Operations. Six smart work zone types were recommended including: Construction Equipment Alert Systems, Queue Detection System, Speed Monitoring System, Travel Time, Incident Detection, and Over-Height Vehicle Warnings. These systems include CCTV cameras, portable dynamic message signs, vehicle detectors, and other emerging technologies (e.g., connected vehicle roadside units). Performance dashboards, providing real time situational awareness of the work zone, would leverage smart work zone systems and contribute to safety and travel reliability benefits. Research has shown that active work zone management can achieve a BCR between 15.0 and 43.0 depending on traffic demand conditions. The contribution of implementing performance dashboards for safety and travel reliability during construction would be a component of this BCR range.

Strategy No. 19: Strengthen TIM Collaboration with Stakeholders to Safely Reduce Incident Clearance Times

BCAs have been conducted for numerous Traffic Incident Management (TIM) programs. The TIM Benefit-Cost (TIM-BC) tool was developed to help State and local transportation engineers, decision makers and other users evaluate and compare the monetary value of different TIM strategies. The TIM-BC tool allows for quick updates to backend calculations and default values and can allow for a more user-friendly interface. Transportation decision makers, transportation engineers and other users can easily assess the benefits and costs of applying each of eight selected TIM strategies by entering the required data.

A New York case study, as part of the I-95 Corridor Coalition, was conducted to compare the effectiveness of implementing three selected TIM strategies, namely: safety service patrol, driver removal laws and dispatch colocation. The results of the study, applying TIM-BC, indicated that Safety Service Patrols have a BCR of more than 18, Driver Removal Law has a BCR of more than seven, and Dispatch Collocation has a BCR of nearly four.

Other TIM BCR studies applied their own unique approach with special assumptions to analyze various TIM strategies for which BCRs range from two to 36. While it is not feasible to conduct a quantitative BCA for this TSMO strategy at this high level, the above provides a methodology, web-based software tool and a framework for conducting such analyses and a range of BCR expectations, as the details of the strategy becomes more defined.

4. Benefit Cost Analysis (Quantitative Method)

As TSMO strategies advance from the TSMO Strategic Plan level to the TSMO Program Plan level, quantitative analyses may be more feasible and applicable. However, as many TSMO strategies are related to business processes, culture and collaboration, it will still be challenging to conduct quantitative BCAs with reliable results. For those TSMO strategies that BCRs apply, the Tool for Operations Benefit Cost Analysis (TOPS-BC) may be used. In other cases, an estimate of benefits and costs may be made outside of an established model. For example, for cybersecurity the cost of a lost day of operation may be estimated. Similarly, estimations of benefits and costs may be made for comprehensive emergency response plans.

Tool for Operations Benefit Cost Analysis (TOPS-BC)

TOPS-BC is a sketch-planning level decision support tool developed by the FHWA Office of Operations. It is intended to be used to conduct BCAs for a wide range of TSMO strategies. The tool was developed based on guidance and input from planning and operations practitioners with the primary purpose to help in screening multiple TSMO strategies and for providing "order of magnitude" BCA estimates. While TOPS-BC is useful for conducting BCAs of “systems and technology” applications, it does not appear that it is relevant to the other CMM dimensions where qualitative analyses are more appropriate. TOPS-BC has templates addressing BCAs for the TSMO strategies listed in Table 6 below.

Table 6: TSMO Strategies Included in TOPS-BC

Traveler Information
En-Route Traveler Information
Pre-Trip Traveler Information
Traffic Signal Systems
Preset Timing
Traffic Actuated Timing
Central Control
Transit Signal Priority
Ramp Metering
Central Control
Traffic Actuated
Preset Timing
Freight Strategies
Truck Only Lanes
Compliance
Truck Parking and Reservation Systems
Truck Climbing Lanes
Off Hours Delivery

Table 6: TSMO Strategies Included in TOPS-BC (cont.)

Active Traffic Management
Variable Speed Limits
Part-Time Shoulder Use
Other Strategies
Traffic Incident Management
Travel Demand Management
HOT Lanes
Road Weather Management
Work Zone Management
Shared Use Mobility

TOPS-BC is intended to provide a framework for analysts that can be modified and configured to match the needs of the districts and the characteristics of the area being analyzed. Default data is provided for many impact parameters, performance relationships and benefit valuations. Such default data are typically based on national averages or accepted values. However, opportunities are provided to use locally configured or regionally relevant data where appropriate and desired. TOPS-BC includes the general parameters and benefit valuations as shown in Table 7 below. The USDOT publication Benefit-Cost Analysis Guidance for Discretionary Grant Programs (January 2020) also provides unit rates for the following parameters which may be used as a comparative source.

Table 7: TOPS-BC Parameters and Default Values

TOPS-BC Parameters	TOPS-BC Default Values
General Parameters	
Year of Dollar Displayed	2019
Inflation Rate	2.5%
Percentage Trucks	10%
Average Auto Occupancy	1.67
Discount Rate	7.0%
Analysis Time Horizon	20 years
Benefit Valuations	
“On the Clock” Travel Time	$37.58 per hour
Other Auto Travel Time	$15.29 per hour
Truck Travel Time	$29.96 per hour
Crash - Fatality	$12,282,140 per occurrence
Crash – Injury	$355,842 per occurrence
Crash – Property Damage Only	$12,829 per occurrence
Fuel Cost	$2.82 per gallon (excludes taxes)

TOPS-BC Parameters	TOPS-BC Default Values
Non-Fuel Operating Costs - Autos	$0.27 per VMT
Non-Fuel Operating Costs - Trucks	$0.40 per VMT
Fuel Economy - Autos	26.2 miles per gallon
Fuel Economy - Trucks	18.8 miles per gallon
CO Emissions	$75 per ton
CO2 Emissions	$40 per ton
NOx Emissions	$8,615 per ton
PM Emissions	$357,528 per ton
VOC Emissions	$1,986 per ton
Auto Noise	$0.0012 per VMT
Truck Noise	$0.0355 per VMT

Table 8 provides a representative sampling of unit cost default information for various TSMO strategies.

Table 8: TOC-BC Default Unit Cost Information

TSMO Strategy	Cost Items	Useful Life (yr)	Capital Costs ($)	O&M Annual Costs ($)
Advanced Traveler Information System - Pre-Trip Traveler Information	TMC Hardware and Software	5	26,600	1,310
	Systems Integration	10	105,000	10,000
	Data Management System	10	3,000,000	200,000
	Communications Line	5	770	930
	Variable Message Sign	10	89,000	4,200
	Variable Message Sign Tower	25	100,000	220
Traffic Signal Coordination Systems - Preset Timing	Linked Signal System LAN	20	57,000	1,100
	Signal Controller	10	10,000	340
	Communication Line	5	770	6,800
Traffic Signal Coordination Systems - Traffic Actuated	Linked Signal System LAN	20	57,000	1,100
	Signal Controller	10	10,000	340
	Communication Line	5	770	6,800
	Loop Detectors (2)	5	11,000	4,300
Traffic Signal Coordination Systems - Central Control	Linked Signal System LAN	20	57,000	1,100
	TMC Hardware - Signal Control	5	29,000	1,600
	TMC Software/Integration	5	205,000	
	Labor			600,000
	Signal Controller	10	10,000	340
	Communication Line	5	770	6,800
	Loop Detectors (2)	5	11,000	4,300
Traffic Signal Coordination Systems - Transit Priority	TMC Hardware	5	29,000	1,600
	TMC Software/Integration	20	3,600	
	Labor			210
	Signal Preemption Processor	10	460	10
	Cell Based Communication	10	210	10

Table 8: TOC-BC Default Unit Cost Information (cont.)

TSMO Strategy	Cost Items	Useful Life (yr)	Capital Costs ($)	O&M Annual Costs ($)
Ramp Metering - Central Control	TMC Hardware	5	22,500	2,000
	TMC Software/Integration	5	400,000	
	Labor			100,000
	Roadway and Drainage	25	25,801	
	Signalization	25	78.483	2,500
	Communications	25	9,673	500
	Signing and Marking	25	4,894	250
	Traffic Control	25	4,575	
Ramp Metering - Traffic Actuated	TMC Hardware	5	18,000	1,600
	TMC Software/Integration	5	77,000	
	Labor			56,000
	Ramp Meter (Signal, Controller)	10	30,000	1,900
	Loop Detectors (2)	10	20,000	480
	Communication Line	5	770	260
Ramp Metering - Preset Timing	Ramp Meter (Signal, Controller)	10	30,000	1,900
	Loop Detectors (2)	10	20,000	480
Active Transportation Demand Management – High Occupancy Toll (HOT) Lanes or Truck Only Lanes	TMC Lane Control Hardware	5	8,200	1,200
	TMC System Integration	10	260,000	
	TMC Lane Control Software	2	36,000	770
	TMC Labor			110,000
	Toll Processing H/W and S/W	10	128,500	2,370
	Toll Processing Center Labor			110,000
	Communications	5	2,820	2,980
	Variable Message Sign	10	89,000	4,200
	VMS Tower	25	100,000	220
	Lane Signal Controller	10	85,000	1,900
	Loop Detectors (2)	10	10,500	480
Freight Strategy Costs - Parking & Reservation	Detectors, Cameras, Sensors	5	150,000	15,000
	Communications	5	50,000	17,000
	Dynamic Message Signs	10	100,000	10,000
	Systems Integration	10	60,000	6,000
	Network Equipment	10	20,000	2,000
	Signage	10	16,000	1,600
	Utilities		25,000	2,500
	Operational Support			18,000
	Preventive Maintenance			24,000
	Software Maintenance/License			12,000
Traffic Incident Management – HERO Service Patrol	Incident Detection Monitors	5	2,800	140
	TMC Incident Response H/W	5	2,500	120
	TMC System Integration	20	205,000	
	TMC Incident Response S/W	2	15,300	770
	Communications			110.000
	EOC H/W and S/W	10	145,000	2,660
	Emergency Response Labor			111,000
	Incident Response Vehicle	7	87,000	15,500
	Incident Response Labor			96,000

Table 8: TOC-BC Default Unit Cost Information (cont.)

TSMO Strategy	Cost Items	Useful Life (yr)	Capital Costs ($)	O&M Annual Costs ($)
Active Transportation Demand Management - General Costs	Engineering Design	25	1,700,000	
	Software Module	10	305,000	3,100
	Traffic Engineering/Operations	10	39,000	39,000
	ATM TOC Hardware	10	41,000	1,000
	Harden Shoulder	25	2,500,000	62,000
	Ramp Meters	10	29,000	720
	Arterial and Ramp Detection	10	9.600	240
	Gantries with Large DMS, CCTV	25	1,400,000	285,000
	Controller	10	360,000	18,000
	Speed Limit/LCS on Gantry	10	430,000	21,500
	Detectors on Gantry or Pole	10	430,000	21,500
	Mast Arm w/Dynamic DLA Signs	10	145,000	7,200
	Roadside Signs, Controller, Post	25	19,000	960
	Camera Assembly	10	62,400	3,100
	Telecon/Power Duct	25	960,000	24,000
	Telecommunications	25	620,000	12,500
	Power (trunk to device)	25	580,000	5,800
	Onsite Backup Generator/UPS	10	145,000	3,600
Travel Demand Management - Employer Based Programs	Information Center Hardware	5	50,000	1,000
	Info Center System Integration	5	82,000	
	Info Service Center Software	10	305,000	23,000
	Map Database Software	2	23,000	
	Employer Outreach	1		325,948
	Grassroots Marketing	1		264,755
	Transit Store/Call Center	1		425,187
	Commute Assistance/ Subsidy	1		59,304
	Regional Bikeshare	1		35,938
	Training, Travel, Admin	1		19,522
Active Transportation Demand Management - Part-Time Shoulder Use	TMC Lane Control Hardware	5	8,200	1,200
	TMC System Integration	10	260,000	
	TMC Lane Control Software	2	36,000	770
	TMC Labor			110,000
	Communications	5	2,820	2,980
	Variable Message Sign	10	89,000	4,200
	Variable Message Sign Tower	25	100,000	220
	Lane Signal Controller	10	85,000	1,900
	Loop Detectors (2)	5	10,500	480
Road Weather Management	TMC Information H/W and S/W	5	26,600	1,310
	TMC System Integration	10	77,000	5,000
	Labor for Traffic Information			110,000
	Communications	5	4,870	3,230
	Variable Message Sign	5	89,000	4,200
	Variable Message Sign Tower	25	100,000	220
	Remote Weather Station	10	38,000	2,400

Table 8: TOC-BC Default Unit Cost Information (cont.)

TSMO Strategy	Cost Items	Useful Life (yr)	Capital Costs ($)	O&M Annual Costs ($)
Work Zone Management	TMC Information H/W and S/W	5	26,600	1,310
	TMC System Integration	10	77,000	5,000
	Labor for Traffic Information			110,000
	Communications	5	4,870	3,230
	VMS – Temporary	10	24,000	1,200
	Video Camera	6	8,100	1,100
	Camera Tower	20	40,000	380
Shared Use Mode	Bikeshare: per100 bike system	5	4,500	450
	Carsharing City Payment	1	1,800	
	Bikeshare, Systems Operations	1	1,371,000	
	Bikeshare Mgmt and Marketing	1	103,000	
Support Strategies - Traffic Management Center	Traffic Management Center	20	3,800,000	385,000
Support Strategies - Loop Detection	Traffic Monitoring H/W and S/W	5	120,000	6,100
	System Integration	10	200,000	10,000
	Loop Detector (double set)	5	24,000	2,100
	Communication Line	5		2,600
Support Strategies - CCTV	Traffic Monitoring H/W and S/W	5	165,000	8,300
	System Integration	10	200,000	10,000
	Video Camera	10	43,000	1,100
	Camera Tower	20	40,000	380
	Communication Line	5		2,600

For more information on how to apply the TOPS-BC tool, please refer to the FHWA publication TSMO, Benefit Cost Analysis Compendium (2015) or the FHWA website https://ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm.

BCA Before & After Studies

BCA "Before & After" studies should be conducted on TSMO strategies after they are implemented to determine how well they are performing. These assessments should be based on qualitative and quantitative performance measures and targets, as applicable. Based on these studies, the TSMO strategy may be modified, expanded or eliminated from further consideration. Successful implementation of a "before & after" study requires good documentation of the base case performance, using the same metrics that will be examined in the "after" analysis. Comparison of the "before" BCR and the "after" BCR also requires validation that the facility is operated as expected in the "before" assessment. Consider the following questions: did the project open on schedule, were complementary investments in place as expected, and did the surrounding economy grow as anticipated? If not, adjustments need to be made to ensure an "apples to apples" before and after comparison.

In addition, operational dashboards should be monitored to determine whether or not TSMO strategies are having a positive impact on performance. Traffic Management Systems (TMS) performance metrics that metro districts are required to track, and urban and rural districts are encouraged to consider, include:

- Asset uptime
- Incident clearance time
- Travel time reliability

These performance dashboards are posted on TxDOT's website. Sample dashboards are presented for March 2020 in Figure 3.

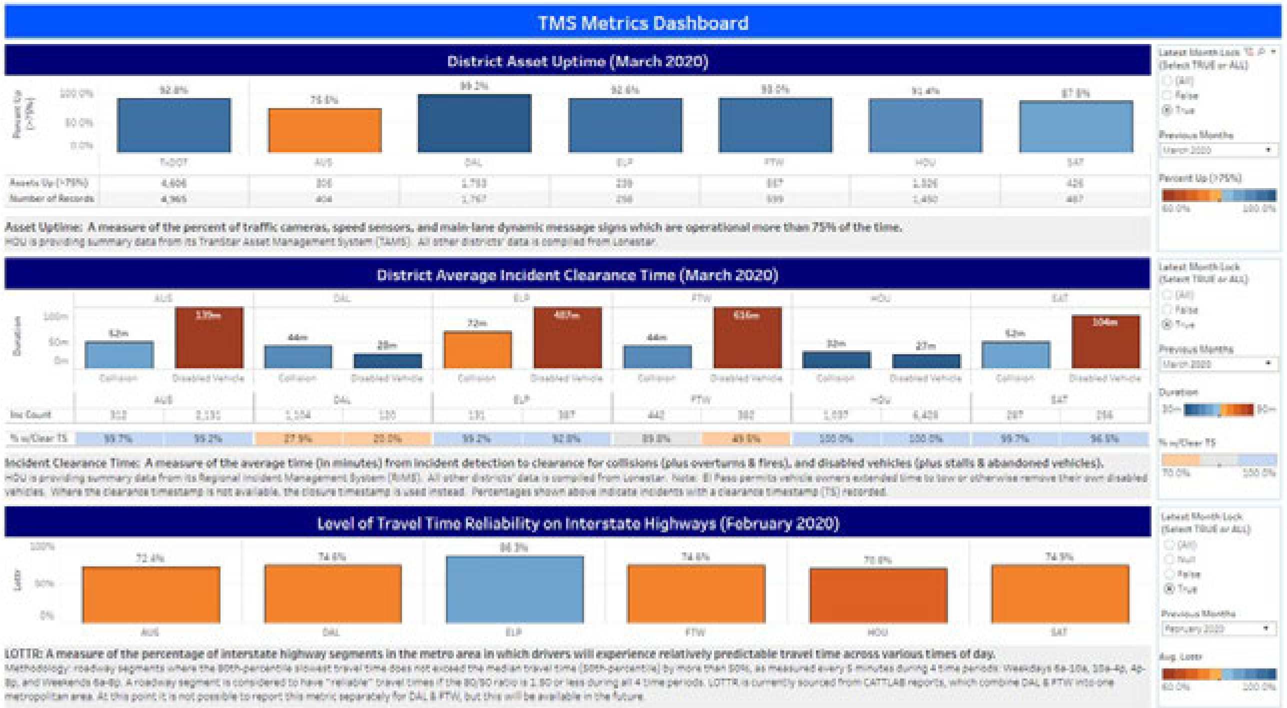


Figure 3: TxDOT Traffic Management System Performance Dashboards

As District TSMO Program Plans are prepared, additional performance measures are expected to be identified to correlate with the District's TSMO goals and strategies. Specific targets should be developed for each performance measure with actual versus target reported on a regular basis. By monitoring performance dashboards, and conducting BCA "before & after" studies, a continuous improvement program should be implemented in achieving higher levels of capability maturity for each of the applicable CMM dimensions.

5. Summary and Next Steps

In summary, while there are quantitative tools available to conduct BCAs for TSMO projects, they do not appear to be applicable for many TSMO strategies at the Strategic Plan level. The TSMO strategies presented in the Strategic Plan are aligned with the six dimensions of the CMM analysis framework. Therefore, the BCAs presented in this technical memorandum provides qualitative benefits, costs and BCRs (i.e., high, medium, low). References are made to case studies in other states where significant deployment and O&M costs were realized.

As TSMO tactical plans advance to the more detailed development stage, the BCA methods referenced in Section 4 should be considered and applied, where applicable. In other cases, an attempt at estimating benefits and costs should be made where data is available. After the TSMO strategy is implemented, BCA “before & after” studies, combined with monitoring performance dashboards, should be conducted to drive continuous improvement towards achieving higher levels of capability maturity.

Based on the qualitative BCA conducted as part of this technical memorandum, the following five initiatives are recommended to be advanced within a near-term (e.g., within two years) timeframe:

- **Strategy No.1** - Develop and Apply Methodology to Allocate ITS/Signals O&M Funding to Align with TSMO Goals.
- **Strategy No. 5** - Conduct Cybersecurity Vulnerability Analyses of IT Networks to Improve Resiliency.
- **Strategy No. 10** - Develop Enhanced Traffic Signal System Implementation Plans.
- **Strategy No. 18** - Support Rural District Operations that have Limited Resources to Support TSMO Goals.
- **Strategy No. 19** - Strengthen TIM Teams Collaboration with Stakeholders to Safely Reduce Incident Clearance Times.

Each of the above TSMO strategies are summarized in the Appendix, including next steps for implementation. The lessons learned, including BCAs, will be valuable in applying them to other TSMO strategies as they are implemented in the future.

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USDOT, FHWA, Transportation Systems Management & Operations, Benefit Cost Analysis Compendium, FHWA-HOP-14-032, July 2015.

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FHWA, Office of Operations Research and Development, User-Friendly Traffic Incident Management (TIM) Program Benefit-Cost Estimation Tool, FHWA-HRT-16-055, prepared by Leidos, Inc., January 2016.

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Appendix: Recommended TSMO Strategies to be Implemented in Near-Term

Strategy No. 1: Develop and Apply Methodology to Allocate ITS/Signals O&M Funding to Align with TSMO Goals.

Funding to cover operations and maintenance (O&M) costs for ITS and traffic signals significantly lags the amount of ITS infrastructure being added within the districts. District O&M funding are discretionary and often times used for roadway maintenance rather than ITS. There is currently no dedicated funding source for TSMO as it relies on mainstreaming as part of other transportation improvement projects.

As the success of TSMO is largely dependent on leveraging the ITS infrastructure, the manner that O&M funds are allocated to the districts should be revisited. A methodology should be developed for O&M funding that considers applicable guidelines in the proposed INVEST in America Act. Consideration should be afforded to requesting and programming ITS funds to cover life-cycle costs. Life-cycle costs include initial deployments costs plus O&M costs over the useful service life of the investment. The methodology should provide a template that the districts use to provide an equitable balance of O&M funds for ITS/Signals as compared to roadways, bridges and other TxDOT facilities. In addition, methods for charge backs should be considered when contractors damage critical ITS infrastructure including communications (e.g., fiber).

Next Steps:

1. **Research annual funding allocations versus needs for each district**
   Funding requirements to support existing and proposed ITS infrastructure should account for O&M expenses for all ITS devices. This includes CCTV cameras, vehicle detectors, dynamic message signs, road weather information systems, communications as well as other field devices. In addition, O&M expenses should include the costs for TMC operations and maintaining the supporting IT infrastructure. An amortized budget should also be allocated for replacing ITS/IT equipment at the end of service life.

2. **Review the proposed INVEST in America Act to identify eligible funding sources**
   The proposed INVEST in America Act provides $494 billion over five years for surface and rail transportation investments. Included is $411 billion over five years from the Highway Trust Fund for highway, transit, safety and research programs, a 46 percent increase over current investment levels. The Act strengthens the role of ITS technology as eligible activities under several federal-aid funding programs. The proposed Act is expected to be approved by the end of 2020. TxDOT should closely monitor the proposed INVEST in America Act as it advances through the approval process and advocate for lifecycle and TSMO funding support.

3. **Develop five-year funding program that considers annual ITS O&M and replacements**
   Each district should forecast their ITS O&M funding needs during the next five-year timeframe. TxDOT's Traffic Safety Division (TRF) should provide general guidelines to prepare these forecasts and share anticipated estimates of funding availability. The guidelines should include a methodology to allocate ITS/Signals O&M funding to align with TSMO goals, considering the following parameters:

   - Equitable distribution of funds across metro, urban and rural districts.
   - Alignment of funding based on ITS/Signal O&M needs to address TSMO goals.
   - Funding needs to improve performance metrics in achieving statewide and district targets.
   - Adoption of statewide standards for procuring emerging technologies.
   - Maintenance agreements with local operating agencies.

   TRF should also serve in an arbitration role to allocate O&M funding where shortfalls are expected. Allocation of funds should be based on the above parameters as well as business rules that are adopted.

Strategy No. 5: Conduct Cybersecurity Vulnerability Analyses of IT Networks to Improve Resiliency.

Some of the greatest management challenges facing the public and private sectors today are from persistent and advanced cyber threats. Today's dynamic threat environment requires integrated solutions, aligned closely to industry-specific operations and critical business functions. The challenge is understanding potential vulnerabilities and making informed, critical decisions on what and where to budget for security and resilience of assets, systems and networks.

On May 14, 2020, TxDOT was subjected to a ransomware event. Through swift action, TxDOT was able to stop the ransomware event and limit its impact on the information technology systems. TxDOT was quick to act to investigate, analyze and remediate the situation. This event caused temporary interruptions on the agency network as well as business and traffic applications. Unfortunately, cybersecurity and ransomware events are an increasingly common occurrence. Therefore, it is recommended that recurring vulnerability analyses be conducted on a regular basis to provide life-cycle protection of critical infrastructure from every type of risk: deliberate, accidental and natural. Vulnerability analyses should consider cyber, wireless and physical domains including identifying vulnerabilities and weaknesses within each domain, focusing in on gaps and seams, and aligning critical processes with critical technologies to ensure business continuity through improved resilience, preparedness, detection and response.

Next Steps:

1. **Conduct after action review of the May 14, 2020 ransomware event**
   After action reviews should be led by the Information Technology Division (ITD) with input obtained from each applicable TxDOT division to identify possible vulnerabilities, their impacts and how to address and prevent them in the future.

2. **Develop (or modify) processes and checklists to conduct vulnerability analyses**
   Cybersecurity vulnerability analyses of IT Networks should address risk and security, incorporating a repeatable method of identifying and aligning assets with critical business processes and leverage best practices of industry and government methodologies and standards. Processes and checklists should be developed in coordination with TxDOT divisions and districts to frame, assess, remediate and monitor risk focusing on those critical business processes that have the greatest impact to TxDOT operations. These processes and checklists should address the following as a minimum:

   - Identify IT Assets (e.g., people, equipment, data, systems, networks, intellectual property)
   - Identify and Evaluate Threats (e.g., viruses, malicious coding, natural disasters, people)
   - Identify and Evaluate Vulnerabilities (e.g., outdated virus software, infrequent backups)
   - Identify and Evaluate Privacy Issues (e.g., unauthorized access to personal data stored)
   - Develop or Update Security Policies (e.g., policies, procedures, risk assessments)
   - Implement Change Management (e.g., addition/changes of network and software components)
   - Ongoing Maintenance (e.g., regular monitoring of system, incident response team)
   - Security Response Team (e.g., monitoring vendor software updates, review network patches)

3. **Conduct cybersecurity vulnerability analyses on a regular basis**
   ITD should take the lead in developing and applying cybersecurity vulnerability analyses in compliance with an adopted schedule of audits. Audits should apply the processes and checklists as they pertain to all types of threats including, but not limited to unauthorized external access, unauthorized internal access, accidental system change, incorrect configuration, viruses, information leakage, environmental control failures, physical access, remote access and social engineering.

Strategy No. 10: Develop Enhanced Traffic Signal System Implementation Plans.

The National Transportation Operations Council's "2012 National Traffic Signal Report Card" includes a self-assessment of 241 respondents representing 39% of all traffic signals throughout the United States. The average grade was D+ across five categories: management (D), traffic signal operations (C), signal timing practices (C), traffic monitoring and data collection (F), and maintenance (C). This was an update of a similar survey conducted during 2007 where the average self-assessment grade was D-. Enhanced Traffic Signal System Implementation Plans should be prepared to achieve the following goals:

- Enhance operational consistency and reliability to improve traffic operations along state roads
- Reduce asset downtime due to incidents, malfunctions, and end-of-life equipment replacement
- Apply Automated Traffic Signal Performance Measures (ATSPM) to systematically improve operations
- Enable active traffic management along appropriate corridors
- Reduce delays and queueing due to major incidents
- Ensure new technologies provide a good return on investment compared to legacy devices
- Improve coordination with municipal traffic signal systems
- Provide security upgrades to reduce the risk of hacking or theft at traffic signal cabinets

Next Steps:

1. **Prepare Statewide Enhanced Traffic Signal System Implementation Plan**
   A Statewide Enhanced Traffic Signal System Implementation Plan should be prepared to support TSMO goals. Specifically, the Plan should address traffic signal system technologies, system software, traffic control strategies, TMC operations and maintenance in alignment with performance outcomes as a basis for tracking the systems performance. The Plan should focus on the following goals: (1) leadership activities in developing policies and guidance on arterial system safety and mobility; (2) safety in reducing vehicle-vehicle crashes as well as bicycle and pedestrian crashes; (3) mobility to improve travel time reliability and reduce congestion; and (4) systems availability via monitoring, operations, and proactive maintenance.

2. **Prepare District Enhanced Traffic Signal System Implementation Plans**
   District TSMO Program Plans will identify the need for the district to prepare Enhanced Traffic Signal System Implementation Plans. These Plans should apply the Statewide Plan as a framework to customize at the district level.

3. **Implement District Enhanced Traffic Signal Implementation Plans in phases**
   Implementation Plans should be prepared to address the following in phases for each district:

   - **Field Technologies** - communications to signals; upgrade of traffic controllers to accommodate Connected Vehicle (CV) capabilities; plan for testing and evaluation of emerging technologies; and implementation of pilot projects along strategic corridors.
   - **Traffic Control** - actively manage and operate strategic corridors using remote access to signals by identifying staff resource needed; implementing the ATSPM tool; implementing traffic adaptive where applicable; and accommodate CV capabilities.
   - **TMC Technologies** - actively manage and operate freeway and arterial corridors leading to ICM by developing an arterial system operation module within Lonestar™ ATMS; develop and implement application program interface to connect local systems; develop and implement dashboard application; develop and implement decision support system for ICM; and develop and implement data management plan including maintenance.
   - **Operations & Maintenance (O&M)** - provide proactive O&M for strategic corridors by developing staffing resources plan for O&M; and developing O&M baselines and performance goals.

   While the above efforts should be closely coordinated between TRF and TxDOT Districts, some of these will be led by TRF and some by the Districts.

Strategy No. 18: Support Rural District Operations that have Limited Resources to Support TSMO Goals.

TSMO strategies should be developed to encourage rural districts to partner with neighboring districts (or border states) to share operational responsibilities and assets during emergencies. This may include providing DMS messages, TMC operations, and incident response as rural districts may not have the resources to address these issues in a timely manner.

A checklist should be developed and provided to rural districts to offer guidance in what to request in terms of ITS infrastructure when they are developing a roadway improvement project. Furthermore, they may desire to share in the development and maintenance of asset management systems. Rural districts may also need support in providing Traffic Incident Management (TIM) training for fire, police and other local emergency responders.

Rural districts often struggle with recruiting and retaining quality maintenance technicians resulting in a high backlog of repairs that are needed which are not being addressed in a timely manner. Partnering agreements with adjacent districts should be considered in addressing this concern.

Next Steps:

1. **Prepare a checklist to offer guidance in requesting ITS as part of roadway improvement projects**
   Checklists should be consistent with the District's TSMO Program Plan and ITS Master Plan. Specifically, the checklists should address the following as a minimum:

   - **ITS Field Devices** - CCTV cameras, vehicle detectors, dynamic message signs, road weather information systems and other technologies to address district safety and mobility needs.
   - **Communications** - wireline, wireless or some combination of the two to provide connectivity between the ITS field devices and a TMC or monitoring workstation.

2. **Provide TIM training for fire, police and other emergency responders**
   Beginning January 1, 2020, the Texas Commission on Law Enforcement requires that all Basic Peace Officer Academies include the FHWA TIM Course and the Texas Commission on Fire Protection mandates that all career and volunteer firefighters must complete the FHWA TIM course by December 1, 2020 to retain their state certification. The Texas goal set for 2020 is to have 65% of all first responders trained by the end of December. As of May 2020, 44,954 first responders have been trained or 57.4% of the 78,309 first responders to be trained. The TxDOT Statewide TIM team coordinates and facilitates agency training promoting a shared understanding of the requirements for safe, quick clearance at traffic incident scenes; prompt, reliable and open communications; and motorist and responder safeguards. The training focuses on a response effort that protects motorists and responders while minimizing the impact on traffic flow. Specifically, the training addresses detecting, verifying and responding to incidents; clearing the incident scene; and restoring traffic flow, it is delivered as a four-hour course and includes interactive seminars; case study analysis; tabletop role-play and scenarios; and field practicums that focus on the safety of responders and drivers, quick clearance and effective communications at traffic incident scenes. TIM training should include refresher training on a regular basis and be expanded in covering local agencies, towing and other first responders in each district.

3. **Develop partnering agreements among districts to share maintenance technicians**
   As TSMO Program Plans are prepared for each district, they should be reviewed by TRF to identify where it makes sense for bordering districts to partner in sharing resources, particularly where staff and ITS resources are limited. These partnering agreements may cover the following as a minimum:

   - Shared technicians to provide preventive, corrective and emergency ITS/Signals maintenance
   - Shared operations to provide the required resources to address severe or lane blocking events
   - Regional TIM teams to address cross-district planned and unplanned events
   - Freight corridors which span multiple bordering districts
   - Emergency evacuation corridors where there are inter-dependencies on bordering districts.

Strategy No. 19: Strengthen TIM Teams Collaboration with Stakeholders to Safely Reduce Incident Clearance Times.

The TxDOT Statewide TIM Team is managed by TRF who communicates and coordinates best practices, training and national programs with the six metro regions. Houston and Dallas Councils of Government administer the TIM teams and training. San Antonio and Fort Worth have a full-time TIM Coordinator. The Austin TMC/HERO consultant is managing the TIM team. The El Paso TIM team is managed by TxDOT TMC/ITS staff. Meeting agendas that focus on quick clearance initiatives allow first responders to learn and practice the TIM National Unified Goal when at crash scenes. Dedicated full time TIM Coordinators manage agency outreach, meetings, speakers, after-action-reviews, training and documentation. Currently, data fields are being added to law enforcement Crash Records Information System (CRIS) reports to capture incident timelines, secondary crashes and first responders struck-by incidents.

A Statewide TIM Strategic Plan should be prepared to address deficiencies noted by FHWA TIM Self-Assessment surveys. This plan should address TSMO strategies to improve communications and incident notifications with stakeholders. This may include developing interagency agreements to strengthen agency partnerships, developing effective communications plans and SOPs, and assessing TMC/TIM integrated operations in making recommendations to improve their effectiveness.

Next Steps:

1. **Develop TIM strategic plan to address FHWA TIM Self-Assessment deficiencies**
   TxDOT, as well as other State DOTs, apply the FHWA TIM Self-Assessment tool to identify areas needing improvement in making the TIM program more effective. A Statewide TIM Strategic Plan should be prepared that provides specific recommendations for each aspect of the TIM program, including program and institutional issues; operational issues; communications and technology issues; and the HERO/Safety Service Patrol/Courtesy Patrol program. The TIM Strategic Plan would also include performance measures to provide guidance on recommended action items as well as provide metrics to drive continuous improvement.

2. **Develop and execute interagency agreements to strengthen agency partnerships**
   Interagency agreements are needed between the TIM partners to address the incident command structure, equipment staging, traffic control, hazardous materials incident issues and procedures, crash investigation procedures, quick clearance procedures and many other issues. The development of TIM agreements can be more challenging than expected. Many agencies are involved and may have competing or conflicting priorities. The path to agreements is generally forged from a better understanding of these conflicting priorities and should be undertaken in a five-step process.

   - Step 1 - Fully understand the goals of agencies involved with the primary types of incidents. Once this is understood, prepare a matrix outlining the agencies involved in each incident type.
   - Step 2 - Fully understand competing priorities across all agencies. Build consensus by relying on stakeholder meetings to collect a list of priorities by agency and resolve conflicts as a group.
   - Step 3 - Identify a collective set of priorities, then discuss how all agencies can work together within a framework of incident management, and prioritized incident clearance.
   - Step 4 - Identify a set of performance measures for all phases of incident management. Apply these performance measures to identify a program of continuous improvement.
   - Step 5 – Develop agreements that not only address common understanding, but also identifies how Incident management will be assessed, measured and further improved.

3. **Assess TMC/TIM integrated operations to improve their effectiveness**
   Traffic Incident Management is most effective when TMC operations and TIM programs are integrated. This may be in the form of embedding TIM Coordinators as part of TMC operations staff. At a minimum, TIM team meetings should have active participation by TMC operations staff share in the development of SOPs and performance measures, play a key role in after action reviews, and share in joint training programs.