TxDOT Statewide TSMO: Cooperative Automated Transportation Integration

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Document Control

Date	Version	Description
8-13-20	1.0	Traffic Operations Safety Division Review (Prepared by AECOM)
12-15-20	2.0	Addresses TRF Review Comments on Version 1.0 (Prepared by AECOM)
2-09-21	3.0	Address AECOM Review Comments

List of Acronyms

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
ABC	Automated Bus Consortium
ADS	Automated Driving System
AI	Artificial Intelligence
AID	Accelerated Innovation Deployment
AIM	Accelerating Innovative Mobility
ATCMTD	Advanced Transportation & Congestion Management Technology Deployment
CASE	Connected, Automated, Shared, Electric
CAT	Cooperative Automated Transportation
CAV	Connected Automated Vehicle
CCTV	Closed Circuit Television
CMAQ	Congestion Mitigation and Air Quality
CMM	Capability Maturity Model
ConOps	Concept of Operations
COVID	Coronavirus Disease
CRIS	Crash Records Information System
CRCS	Connected Roadway Classification System
C-V2X	Cellular Vehicle-to-Everything
DMP	Data Management Plans
DMS	Dynamic Message Sign
DSRC	Dedicated Short Range Communication
DSS	Decision Support System
FAST Act	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
FSP	Freight Signal Priority
FTA	Federal Transit Administration
GIS	Geographic Information System
HSIP	Highway Safety Improvement Program
ICM	Integrated Corridor Management

Acronym	Definition
IMI	Integrated Mobility Innovation
IoT	Internet of Things
ITD	Information Technology Division
ITS	Intelligent Transportation Systems
LCE	Low Cost Enhancement
LRTP	Long Range Transportation Plan
ML	Machine Learning
MPO	Metropolitan Planning Organization
MUTCD	Manual of Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Transportation Safety Administration
NHPP	National Highway Performance Program
ODD	Operational Design Domains
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
P3	Public-Private Partnership
PS&E	Plans, Specifications & Estimates
PSEMP	Project Systems Engineering Management Plan
RWIS	Road Weather Information System
SAE	Society of Automotive Engineering
SCMS	Security Credential Management System
SHRP	Strategic Highway Research Program
SME	Subject Matter Expert
SOP	Standard Operating Procedures
SPaT	Signal Phasing and Timing
STBG	Surface Transportation Block Grant
STSFA	Surface Transportation System Funding Alternatives
TIM	Traffic Incident Management
TMC	Transportation Management Center
TMS	Traffic Management System

Acronym	Definition
TRF	Traffic Safety Division (Central Office)
TRL	Technology Readiness Level
TSMO	Transportation Systems Management & Operations
TSP	Transit Signal Priority
TTP	Texas Transportation Plan
TxDOT	Texas Department of Transportation
UTP	Unified Transportation Program
V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-Everything
VMT	Vehicle Miles Traveled
VRU	Vulnerable Road Users
WWD	Wrong-Way Driver

Executive Summary

This document has been prepared to support the TxDOT Traffic Safety Division's (TRF) complimentary Transportation Systems Management & Operations (TSMO) and Cooperative Automated Transportation (CAT) programs. Each program has generated several strategic initiatives with the goal of improving safety and mobility for all modes of transportation throughout Texas and are detailed in their respective strategic plans. The 35 CAT strategies that have been identified support the 20 TSMO strategies in a variety of ways over different timeframes. This document describes these relationships and offers recommendations for how the CAT program can be leveraged to support TxDOT's TSMO efforts. Specifically, CAT strategies were identified that support each of the 20 identified TSMO strategies and are listed in Table 1 below. This table also illustrates how the various timeframes for implementation of the CAT and TSMO strategies correlate.

Table 1: CAT Strategies Supporting TSMO Strategies

TSMO	1	Develop Methodology to Allocate ITS/Signals O&M Funding to Align with TSMO Goals	Near
CAT	1	Institutionalize TxDOT's CAT Program	Immediate
	8	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs	Near
	9	Pursue Public-Private Partnerships for Technology Development and Deployment	Near
	11	Support and Provide Internal Funding for CAT Initiatives	Mid
	12	Prepare for Changes in Revenue Streams Due to CAT Proliferation	Mid
	24	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies	Immediate

TSMO	2	Develop Statewide Standard Operating Procedures to Improve Operational Interoperability	Mid
CAT	1	Institutionalize TxDOT's CAT Program	Immediate
	3	Implement Robust Security and Privacy Policies	Immediate
	4	Identify Regulatory Policies that May Impact CAT Implementation	Near
	5	Develop Statewide Guidance for CAT Project Planning and Implementation	Near
	6	Update Existing Design Manuals and Standards to Accommodate CAT Deployments	Near
	7	Explore CAT Impacts on Border Crossing Policies and Procedures	Mid
	26	Develop Common Data Standards and Influence their Widespread Adoption	Near
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near

TSMO	3	Improve Procurement Processes to Support TSMO Program Objectives	Near
CAT	11	Support and Provide Internal Funding for CAT Initiatives	Mid
	34	Incorporate CAT Design, Construction, Operations and Maintenance into Procurement Rules and Policies	Near
	35	Support Flexible and Agile Procurement Practices	Near

TSMO	4	Develop Emergency Response Plan to Improve Preparedness, Response and Recovery	Near
CAT	1	Institutionalize TxDOT's CAT Program	Immediate
	18	Prepare Traffic Management System for CAT Readiness	Immediate
	19	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors	Near
	20	Build Communications Readiness into Roadway Construction Projects	Mid
	21	Support the Provision of Statewide Communications Availability	Mid
	29	Explore CAT Applications that Benefit Multimodal Travel	Mid
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
TSMO	5	Conduct Cybersecurity Vulnerability Analyses of IT Networks to Improve Resiliency	Near
CAT	3	Implement Robust Security and Privacy Policies	Immediate
	24	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies	Immediate
	25	Update Existing Data Management Strategies to Address the Unique Challenges of CAT and Capitalize on CAT Data Opportunities	Near
	26	Develop Common Data Standards and Influence their Widespread Adoption	Near
TSMO	6	Conduct Connected Roadway Classification System (CRCS) Analysis to Prepare for CAT	Near
CAT	5	Develop Statewide Guidance for CAT Project Planning and Implementation	Near
	8	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs	Near
	18	Prepare Traffic Management System for CAT Readiness	Immediate
	22	Strategically Allocate Space for Electric Vehicle (EV) Charging Infrastructure	Mid
	24	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies	Immediate
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
TSMO	7	Develop Artificial Intelligence (AI)/Machine Learning Applications that Address Common Operational Scenarios	Mid
CAT	25	Update Existing Data Management Strategies to Address the Unique Challenges of CAT and Capitalize on CAT Data Opportunities	Near
	26	Develop Common Data Standards and Influence their Widespread Adoption	Near
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
TSMO	8	Increase Intelligent Transportation Systems (ITS) Support by TRF to the Districts to Improve Asset Uptime	Near
CAT	8	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs	Near
	17	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas	Mid
	18	Prepare Traffic Management System for CAT Readiness	Immediate
	19	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors	Near
	20	Build Communications Readiness into Roadway Construction Projects	Mid
	21	Support the Provision of Statewide Communications Availability	Mid
	23	Explore Design Options to Incorporate CAT Operations	Mid

TSMO	9	Develop and Implement ICM along Applicable Strategic Corridors	Mid
CAT	17	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas	Mid
	19	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors	Near
	20	Build Communications Readiness into Roadway Construction Projects	Mid
	28	Enhance Visibility of Vulnerable Road Users in CAT Project Areas	Near
	30	Explore Next Generation Mobility Hub Concepts	Long
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
TSMO	10	Develop Enhanced Traffic Signal System Implementation Plans	Near
CAT	3	Implement Robust Security and Privacy Policies	Immediate
	5	Develop Statewide Guidance for CAT Project Planning and Implementation	Near
	8	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs	Near
	18	Prepare Traffic Management System for CAT Readiness	Immediate
	19	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors	Near
	23	Explore Design Options to Incorporate CAV Operations	Mid
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
TSMO	11	Implement Lonestar™ Enhancements	Mid
	24	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies	Immediate
	25	Update Existing Data Management Strategies to Address the Unique Challenges of CAT and Capitalize on CAT Data Opportunities	Near
	26	Develop Common Data Standards and Influence their Widespread Adoption	Near
	27	Expand Upon Efforts to Create an Information Portal for Sharing CAT Initiative Information	Near
TSMO	12	Implement Performance Dashboards for Safety and Travel Reliability During Construction	Near
CAT	27	Expand Upon Efforts to Create an Information Portal for Sharing CAT Initiative Information	Near
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
	33	Identify CAT Impacts and Needs for Smart Work Zones	Mid
TSMO	13	Apply Performance Measures to all Applicable Phases of Project's Life Cycle (Planning-through Operations)	Near
CAT	1	Institutionalize TxDOT's CAT Program	Immediate
	2	Coordinate Emerging Technology Planning Initiatives	Immediate
	5	Develop Statewide Guidance for CAT Project Planning and Implementation	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
TSMO	14	Develop a Succession Plan for Essential Staff to Provide Continuity of Operations	Near
CAT	1	Institutionalize TxDOT's CAT Program	Immediate
	8	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs	Near
	11	Support and Provide Internal Funding for CAT Initiatives	Mid
	15	Expand Workforce Capabilities with the Provision of CAT Training	Mid
	16	Perform Outreach to Promote Internal and External Acceptance of CAT Initiatives	Mid

TSMO	15	Develop and Maintain a Learning Management System (LMS)	Near
CAT	13	Expand TxDOT's Internal and External Conferences to Feature CAT	Near
	14	Continue to Support and Expand Partnerships with Research Institutions, Academia, Industry and Peer Agencies	Near
	15	Expand Workforce Capabilities with the Provision of CAT Training	Mid
	16	Perform Outreach to Promote Internal and External Acceptance of CAT Initiatives	Mid
	27	Expand Upon Efforts to Create an Information Portal for Sharing CAT Initiative Information	Near
TSMO	16	Apply Gamification Strategies as an Incentive to Continuously Improve Operational Performance	Long
CAT	14	Continue to Support and Expand Partnerships with Research Institutions, Academia, Industry and Peer Agencies	Near
	15	Expand Workforce Capabilities with the Provision of CAT Training	Mid
	17	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas	Mid
TSMO	17	Realize the Full Potential of TxDOT's ITS Infrastructure During Pandemic Events	Near
CAT	1	Institutionalize TxDOT's CAT Program	Immediate
	18	Prepare Traffic Management System for CAT Readiness	Immediate
	19	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors	Near
	20	Build Communications Readiness into Roadway Construction Projects	Mid
	21	Support the Provision of Statewide Communications Availability	Mid
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
TSMO	18	Support Rural District Operations that have Limited Resources to Support TSMO Goals	Near
CAT	5	Develop Statewide Guidance for CAT Project Planning and Implementation	Near
	6	Update Existing Design Manuals and Standards to Accommodate CAT Deployments	Near
	7	Explore CAT Impacts on Border Crossing Policies and Procedures	Mid
	9	Pursue Public-Private Partnerships for Technology Development and Deployment	Near
	10	Support the Pursuit of Federal Grant Funding for CAT Projects	Near
	15	Expand Workforce Capabilities with the Provision of CAT Training	Mid
	17	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas	Mid
	21	Support the Provision of Statewide Communications Availability	Mid
TSMO	19	Strengthen TIM Teams Collaboration with Stakeholders to Safely Reduce Incident Clearance Times	Near
CAT	16	Perform Outreach to Promote Internal and External Acceptance of CAT Initiatives	Mid
	18	Prepare Traffic Management System for CAT Readiness	Immediate
	19	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors	Near
	20	Build Communications Readiness into Roadway Construction Projects	Mid
	29	Explore CAT Applications that Benefit Multimodal Travel	Mid
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near
TSMO	20	Develop Special Event Checklist to Apply TSMO Strategies	Near
CAT	23	Explore Design Options to Incorporate CAT Operations	Mid
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near

1.   Introduction

1.1   *Purpose of Document*

The purpose of this document is to support the TxDOT TRF goal of improving safety and mobility for all modes of transportation throughout the state by providing input on the integration and implementation of the strategies identified in the CAT Strategic Plan into the broader Statewide TSMO Strategic Plan. This document will consider an incremental approach to the integration and implementation of these emerging technologies, while considering, and being responsive to, capability maturity of TxDOT to accommodate emerging technologies as well as the industry to supply the technologies at a high market penetration rate.

1.2   *Background*

Emerging transportation technologies have the potential to fundamentally change the landscape of mobility. Specifically, the introduction of Connected, Automated, Shared and Electric (CASE) vehicles are already transforming entrenched business models and consumer behavior. Through early testing and deployment of these technologies, their potential to create a substantially positive impact on safety, mobility, multimodal connections, and the environmental quality of our nation's transportation system have been demonstrated. The performance of these emerging technologies not only depends on their maturity and readiness for commercial operations, but also on the physical and digital infrastructure that support their functionality, as well as the capability maturity across a number of functions within TxDOT.

While the promises of technologies represent a significant opportunity for infrastructure owners and operators (IOOs), long-term success will depend on strategic investments in the right deployment scenarios. In February 2020, TxDOT prepared a draft CAT Strategic Plan for the State of Texas. This plan includes policies, strategies, pilot programs, and deployments for emerging Connected Vehicle (CV), Automated Vehicle (AV) and Electric Vehicle (EV) technologies. Additionally, TSMO has played an important role in managing, maintaining, and improving the safety and efficiency of existing roadway infrastructure at both the national and state levels.

TSMO is defined by the Federal Highway Administration (FHWA) as "integrated strategies to optimize the performance of existing infrastructure through the implementation of multimodal and intermodal, cross-jurisdictional systems, services, and projects to preserve capacity and improve security, safety, and reliability of a transportation system", TxDOT has adopted the following TSMO vision and mission statements:

- **TSMO Vision Statement:** Improve safety and mobility for all modes of transportation by integrating planning, design, construction, operations, and maintenance activities and acknowledging all opportunities for innovation.

- **TSMO Mission Statement:** Through innovation, collaboration, and performance-based decision making, transportation facilities are developed, constructed, maintained, and operated cost-effectively, with the end user in mind.

The concepts of TSMO and CAT are complimentary, and the strategies developed for implementing a CAT program in Texas will support and enhance the strategies for implementing TSMO Strategies at a statewide level and TSMO program plans at a district level. While each of the 25 districts are developing a District TSMO Program Plan to address their specific needs, the Statewide TSMO Strategic Plan provides the framework to establish

consistency and interoperability. As there will be stand-alone TSMO strategies, it is anticipated that many TSMO strategies will be mainstreamed into existing funding programs during the planning, design, construction, operations and maintenance phases of the project development life cycle, and the inclusion of emerging technologies such as CASE will play a critical role in the years and decades to come.

1.3 Benefits

While significant safety, mobility, social, and environmental improvements are anticipated, CAT technologies will also pose financial, technical and institutional challenges, which are currently being discovered through connected and automated vehicle (CAV) development efforts and studies across the country. Program champions of CAT will work towards implementing technologies that tackle some of Texas' biggest challenges in the areas of safety, mobility, environment, and funding, while executing strategies to combat disruptive changes and impacts. The primary benefits anticipated with CAT implementation include:

- Increasing **SAFETY** with a reduction in roadway crashes and fatalities;

- Improving **RELIABILITY** by minimizing delay and congestion;

- Enhancing **MOBILITY** and access for all Texans with the expansion of transportation options;

- Supporting **AGILITY** by affording TxDOT the ability to adopt beneficial technology in a continuously evolving transportation landscape; and,

- Improving **VITALITY** for the State of Texas with increased efficiencies and cost savings.

CAT represents a transportation system that is comprised of devices, including vehicles, that are cooperative in nature, and contain some level of automation. This automation need not exist within the vehicles but could for example include automated traffic signal re-timing.

2. CAT Strategic Plan Strategies

The CAT Strategic Plan identifies 35 individual strategic initiatives that will help TxDOT prepare for and support the implementation of emerging transportation technologies while meeting the goals of the CAT program, which are organized according to eight focus areas: policy, fiscal responsibility, collaboration, infrastructure readiness, system readiness, multimodal, maintenance & operations, and procurement.
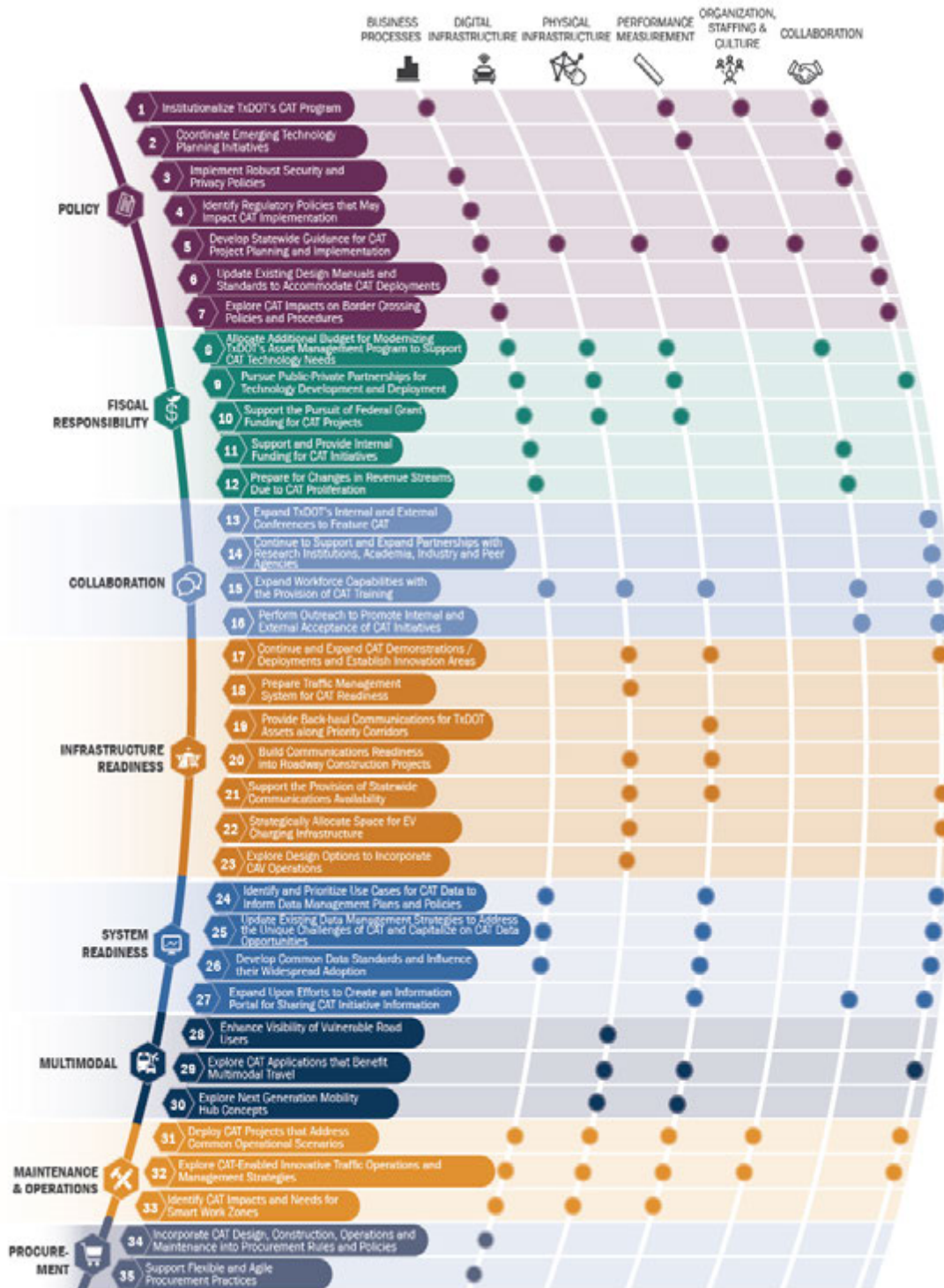

Figure 1 CAT Strategies and CMM Alignment

Although the expansion of CAT technology within the transportation system offers numerous benefits, new challenges can also be anticipated, which may bring about significant change for TxDOT, policy makers, and the industry workforce. These challenges can be addressed through the type of work represented by the TSMO Strategic Plan, and the CAT Strategic and Program Plans, which will enable TxDOT to mitigate some of the risks associated with implementing CAT technologies during a time when those technologies are still changing rapidly. Each of the 35 strategies are targeted to address one of these focus areas, and as shown in Figure 1 in one or more capability maturity model (CMM) dimensions. The standard CMM dimensions were modified slightly in the CAT Strategic Plan, and are shown as column headings, with each strategy mapped to one or more CMM dimension.

Regarding implementation, each strategy is also categorized into one of four timeframes, which align with the various planning process timeframes within TxDOT, as described in Table 2. The CAT Strategic Plan recommends that individual strategies are initiated according to the chart shown in Figure 2 below.

Table 2: CAT Implementation Timeframes

DESCRIPTION	TIMEFRAME	ALIGNMENT WITH TXDOT PLANNING PROCESSES
IMMEDIATE	Now – 2 years	2-Year Operations and Maintenance Schedule
NEAR-TERM	2 – 4 years	Statewide Transportation Improvement Program (STIP)
MID-TERM	5 – 20 years	Unified Transportation Program (UTP) and 2040 Regional Transportation Plan
LONG-TERM	Beyond 20 years	2050 Texas Transportation Plan (TTP)

Category	Strategy	Immediate	Near-Term	Mid-Term	Long-Term
POLICY	01 Institutionalize TxDOT's CAT Program	●			
	02 Coordinate Emerging Technology Planning Initiatives	●			
	03 Implement Robust Security and Privacy Policies	●			
	04 Identify Regulatory Policies that May Impact CAT Implementation		●		
	05 Develop Statewide Guidance for CAT Project Planning and Implementation		●		
	06 Update Existing Design Manuals and Standards to Accommodate CAT Deployments		●		
	07 Explore CAT Impacts on Border Crossing Policies and Procedures			●	
FISCAL RESPONSIBILITY	08 Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs		●		
	09 Pursue Public-Private Partnerships for Technology Development and Deployment		●		
	10 Support the Pursuit of Federal Grant Funding for CAT Projects		●		
	11 Support and Provide Internal Funding for CAT Initiatives			●	
	12 Prepare for Changes in Revenue Streams Due to CAT Proliferation			●	
COLLABORATION	13 Expand TxDOT's Internal and External Conferences to Feature CAT		●		
	14 Continue to Support and Expand Partnerships with Research Institutions, Academia and Peer Agencies		●		
	15 Expand Workforce Capabilities with the Provision of CAT Training			●	
	16 Perform Outreach to Promote Internal and External Acceptance of CAT Initiatives			●	
INFRASTRUCTURE READINESS	17 Continue and expand CAT Demonstrations/Deployments and Establish Innovation Areas			●	
	18 Prepare Traffic Signal Infrastructure for CAT Readiness	●			
	19 Provide Backhaul Communications for TxDOT Assets along Priority Corridors		●		
	20 Build Communications Readiness into Roadway Construction Projects			●	
	21 Support the Provision of Statewide Communications Availability			●	
	22 Strategically allocate space for EV charging infrastructure			●	
	23 Explore the Conversion of Existing Managed Lanes to Dedicated CAT Lanes				●
SYSTEM READINESS	24 Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies	●			
	25 Update Existing Data Management Strategies to Address the Unique Challenges of CAT Data		●		
	26 Develop Common Data Standards and Influence their Widespread Adoption		●		
	27 Expand Upon Efforts to Create a Project Portal for Sharing CAT Initiative Information		●		
MULTIMODAL	28 Enhance Visibility of Vulnerable Road Users		●		
	29 Explore CAT Applications that Benefit Multimodal Travel			●	
	30 Explore Next Generation Mobility Hub Concepts				●
MAINTENANCE & OPERATIONS	31 Deploy CAT Projects that Address Common Operational Scenarios		●		
	32 Integrate CAT into TSMO, Traffic Incident Management (TIM) & Traffic Management Center (TMC) Strategies and Operations		●		
	33 Identify CAT Impacts and Needs for Smart Work Zones			●	
PROCUREMENT	34 Routinely Incorporate CAT Equipment, Services and Policies into Procurement Documentation		●		
	35 Support Flexible and Timely Procurement Standards		●		

Figure 2 Recommended Timeframe for Initiating Individual CAT Strategies

This document addresses CAT Strategy #32 – *"Integrate CAT into TSMO, Traffic Incident Management (TIM) & Traffic Management Center (TMC) Strategies and Operations."* This strategy is shown in Figure 3. Although each recommended CAT strategy has unique characteristics, benefits, and challenges, this specific strategy addresses the need to integrate the CAT program as a whole into other major activities of TxDOT. The specific recommended programs that will accompany each of the CAT strategies are currently under development and will be released as part of the CAT Program Plan under development.

Additionally, the CAT Strategic Plan recommends that strategy #32 is initiated in the "near-term" time frame, and this document will help to articulate a path forward for integrating the wide variety of CAT strategies into the broader TSMO program at TxDOT. CAT technologies will not impact all TxDOT Districts equally or at the same time. Similar to the individual TSMO plans currently being developed for each District, integration of CAT strategies into the statewide TxDOT TSMO Strategic Plan should consider this factor.

STRATEGY 32
Integrate CAT into TSMO, Traffic Incident Management (TIM) and Traffic Management Center (TMC) Strategies and Operations

Identify CAT systems and applications that may improve TSMO, TIM and TMC strategies and operations. Plan and prepare for the integration of CAT into these existing operations by performing a systems engineering analysis to identify affected users, system impacts, changes to operating procedures, etc.

TSMO, TIM and TMC strategies and practices primarily seek to maximize safety for TxDOT's road users, while the foremost potential benefit of CAT is the improvement of safety. Mainstreaming CAT into these practices offers the potential to aligns their needs and goals with the most pertinent solutions.

GOAL ALIGNMENT

SAFETY · RELIABILITY · MOBILITY · AGILITY · VITALITY

COST	STAFF EFFORT
$ $ $	

STAKEHOLDERS

INTERNAL ✓   EXTERNAL ☐

TIMELINE

NEAR-TERM · MID-TERM · LONG-TERM

Figure 3: CAT Strategy #32

3. TSMO Strategic Plan Strategies

The 2020 version of the TxDOT Statewide TSMO Strategic Plan identifies 20 individual strategies, organized according to the CMM focus area that they fall within. These strategies are listed in Table 3 below.

Table 3: TSMO Strategies

Business Processes
1. Develop 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 (CRCS) 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

While TSMO can be very beneficial to metro and urban areas, there is also a need for TSMO in rural areas, which can include minor operational improvements, known as low-cost enhancements (LCEs). Although many of the CAT strategies will affect rural districts, two strategies in particular should be mentioned: **Strategy #5** *Develop Statewide Guidance for CAT Project Planning and Implementation*, and **Strategy #21** *Support the Provision of Statewide Communications Availability*. ITS and traffic signals play a major role in TSMO strategies and are most effective when they are considered during the early stages of project development, sustained over time with

dedicated funding, and optimized via coordination among transportation agencies in the region. Similarly, CAT strategies are most effective if they can be implemented during the early stages of project development and are sustained over time with dedicated funding. However, they also bring significant benefit to the region through the integration of technology and digital infrastructure, and through the coordination with existing programs, like TSMO.

The strategies listed in both the CAT and TSMO Strategic Plans are complimentary. Together they have the capability to revolutionize TxDOT's operations and maintenance for the existing transportation system as well as the future system comprised of vehicles and infrastructure that are more highly connected and automated than at any time in our history. TxDOT has led the initiative nationwide to investigate, integrate, and initiate TSMO and CAT strategies and programs for a state that is geographically and demographically diverse in its transportation needs. The combined 55 strategies between TSMO and CAT cover focus areas from policy to funding to culture and collaboration. This section will examine the ties between these two sets of strategies and discuss the ways they will complement the goals and objectives of each other.

One of the ways to understand the relationship between the 20 TSMO and 35 CAT strategies is through their relationship to the underlying CMM assessments that were performed for each. The CMM is a tool to help agencies identify strengths, weaknesses and next steps for improvement. The six capability dimensions are described in Table 4 below.

Table 4: CMM Dimensions

CMM Dimension	Description
Business Processes	Formal scoping, planning, programming and budgeting
Systems and Technology	Use of systems engineering, systems architectures, standards (and standardization) and interoperability
Performance Measurement	Defining measures, targets, data acquisition, analytics, reporting, and utilization
Organization and Workforce	Programmatic status of TSMO, organizational structure, staff development, recruitment, and retention
Culture	Culture is understanding, leadership, outreach, and program legal authority in a DOT
Collaboration	Relationships and partnering among levels of government and with public safety agencies, local governments, MPOs and the private sector

In the Statewide TSMO Strategic Plan, each strategy is listed under a single dimension, which means its primary focus is addressing that CMM dimension and advancing its maturity, although each TSMO strategy could be applicable to other CMM dimensions. The CAT Strategic plan is structured slightly differently, and each strategy addresses one or more CMM dimensions as illustrated in Figure 1. Aligning the CAT and TSMO strategies based on the CMM dimensions they are targeting then becomes a one-to-many relationship. As the CAT strategies are

currently defined, the ratio of CAT to TSMO strategies is 2:1 for the CMM dimension of Organization, Staffing, and Culture, and 7:1 for the CMM dimension of Collaboration. The individual TSMO and CAT strategies per CMM dimension are detailed in Appendix A – Strategy Tables by CMM Dimension.

CMM Dimension 1 - Business Processes

For the CMM dimension of Business Processes, there are five TSMO and 20 CAT strategies. Each of these strategies are individually tailored for either TSMO or CAT, but as they are addressing the same underlying CMM dimension, they will have areas where they complement each other. Strategies that address this CMM dimension are targeted towards every focus area except Infrastructure Readiness and Multimodal and are heavily represented in both the Policy and Fiscal Responsibility focus areas. Business processes include planning, budgeting, procurement, and process development that are required for CAT programs.

CMM Dimension 2 - Systems and Technology (TSMO), Digital and Physical Infrastructure (CAT)

The second CMM dimension listed in the Statewide TSMO Strategic Plan is called Systems and Technology, which isn't directly mentioned in the CAT Strategic Plan. However, the CAT plan breaks this dimension into two separate dimensions called Digital Infrastructure and Physical Infrastructure. For this analysis, the CAT strategies that fall into either of these groups will be associated with the base CMM dimension listed in the TSMO document. Additionally, the CAT strategies include 12 strategies that address both digital and physical infrastructure, five strategies that address only physical infrastructure, and four strategies that address only digital infrastructure.

CMM Dimension 3 - Performance Measurement

The Performance Measurement CMM dimension includes activities like defining measures, targets, data acquisition, analytics, reporting, and utilization for processes, tools, and programs. This dimension has the fewest overall strategies associated with it: two TSMO and five CAT.

CMM Dimension 4/5 – Organization, Workforce (TSMO) + Culture (TSMO), Organization, Staffing, Culture (CAT)

The CAT Strategic Plan combined the dimensions of Organization and Workforce (O&W), and Culture into the single dimension of Organization, Staffing, and Culture. The Organization and Workforce dimension targets the programmatic status of TSMO, organizational structure, staff development, recruitment, and retention. This focuses on how well the agency (or district) is organized and staffed to carry out TSMO objectives and responsibilities. The Culture dimension, however, is geared towards understanding, leadership, outreach, and program legal authority in a DOT. For example, it considers the questions like "How well is the value of CAT understood throughout the agency (or district)?" and "Is there overall support for TSMO from the agency's leadership?" There are two TSMO strategies and eight CAT strategies associated with these CMM dimensions.

CMM Dimension 6 - Collaboration

The CMM dimension of "Collaboration" was tied with the dimension of "Business Processes." The total number of strategies associated with the two strategic plans is 25 - three strategies from TSMO and 22 strategies from CAT. This dimension looks at the relationships and partnering among various levels of government and with public safety agencies, local governments, Metropolitan Planning Organizations (MPO) and the private sector.
The tables in *Appendix A – Strategy Tables* by CMM Dimension, collectively, represent the relationship between the 20 TSMO strategies and 35 CAT Strategies as they relate to the underlying CMM dimensions, where each

TSMO strategy targets a single CMM dimension and each CAT strategy targets one or more dimensions. The implementation plan for each of these sets of strategies also vary in their recommended timeframe, and in the specific projects and programs recommended to execute each strategy. However, we can find some commonalities as well with respect to the types of strategies that are recommended to begin implementation either immediately or in the near-term (2 - 4 years). The Statewide TSMO Strategic Plan contains 15 strategies that are recommended to begin implementation in the near term, and the CAT Strategic Plan contains five strategies to implement immediately, and 15 strategies to implement in the near term. These plans also list four TSMO and 12 CAT strategies to be implemented in the mid-term (5 - 20 years), and one strategy each for implementation in the long term (beyond 20 years).

With this simple comparison we can see that a lot of activity is recommended to be undertaken over the next four years, implementing 37 individual strategies between TSMO and CAT. In the next section, the CAT strategies will be discussed in terms of practical ways to integrate them into the proposed TSMO strategies given the proposed timeframes for implementation.

3.1 TSMO and CAT Strategy Implementation Timeframe Alignment

The 35 strategies identified in the CAT Strategic Plan include initiatives that should be undertaken to: prepare TxDOT for the integration of emerging transportation technologies into the Texas transportation system; anticipate the impacts on its transportation network, and; position the agency as a leader in emerging technologies and innovation. As discussed previously, the strategies are recommended to be initiated during one of four timeframes, and five CAT strategies are recommended to begin immediately in order to gain momentum towards realizing the vision, mission, and goals of the CAT program. These strategies are listed in Table 5 below according to their individual focus area:

TIMELINE
IMMEDIATE — NEAR-TERM — MID-TERM — LONG-TERM

Table 5: CAT Strategies Recommended for Immediate Implementation

CAT Focus Area	CAT Strategy #	Strategy Description
Policy	1	Institutionalize TxDOT's CAT Program
	2	Coordinate Emerging Technology Planning Initiatives
	3	Implement Robust Security and Privacy Policies
Infrastructure Readiness	18	Prepare Traffic Signal Infrastructure for CAT Readiness
System Readiness	24	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies

Strategies #1, #2, and #3 all fall under the "Policy" focus area, described as legislation, standardization, and institutional culture and practices. Strategy #18 falls under "Infrastructure Readiness", described as the potential for the built environment to enable and enhance CAT, and Strategy #24 falls under "System Readiness" described as the potential for TxDOT digital and institutional systems to enable and enhance CAT. These five strategies, collectively, form the foundation for implementing and integrating a successful CAT program within TxDOT, and will help to ensure sustainable support and leadership of CAT programs, in order to maximize their potential benefits. Furthermore, they reinforce TxDOT as a national leader committed to innovation and maximizing the value of emerging technologies.

Within the Policy focus area, **Strategy #1** is specifically targeted at laying the groundwork for the future of CAT in TxDOT through incremental steps to institutionalizing CAT. This includes designating CAT program champions across TxDOT's Divisions, developing dedicated funding mechanisms, and identifying and dedicating leadership and staff for a CAT office or program who are responsible for realizing the numerous strategies and program initiatives to come. This also supports TSMO strategies related to improving the capability maturity in the dimensions of Organization and Workforce, and Culture, where the TSMO Strategic Plan calls for identifying TSMO champions not only within TxDOT Divisions but also in each District.

Strategy #2 is recommended to maximize collaboration, harmonize initiatives, and eliminate redundancies across planning efforts. Additionally, TxDOT should take on the immediate action of communicating this Draft Strategic Plan and its CAT efforts with internal stakeholders across divisions to facilitate understanding and support across TxDOT.

Strategy #3 addresses the increased cybersecurity threat posed by CAT technologies that are directly tied to TxDOT data infrastructure. Robust security and privacy policies will ensure TxDOT is prepared for potential new threats introduced by these technologies, as well as addressing internal and external data privacy concerns. Without a foundation of security and privacy, many CAT-related programs will be very difficult to develop and maintain.

The other two strategies that are recommended for immediate implementation fall under Infrastructure Readiness and System Readiness, respectively. **Strategy #18** is recommended for preparing the State's traffic signals for emerging CAT technologies, such as connected vehicle Signal Phase and Timing (SPaT) applications, as well as enhancing situational awareness across the transportation system by integrating signal information into core TxDOT functions such as traffic management centers. Connectivity is the backbone of a CAT system, and TxDOT as an IOO plays a critical role in ensuring that data from disparate sources are brought together to inform real-time tactical decisions that enhance overall system functionality and to support broader strategic goals, such as those represented by the TSMO strategies.

Strategy #24 begins to lay the groundwork for the massive data integration work that will be necessary to effectively implement many of the other CAT strategies. This strategy identifies and prioritizes use cases for CAT data to inform a variety of data management plans (DMPs) and policies that are currently underway. This strategy requires the coordination across TxDOT divisions to identify the type, volume, and frequency of roadway

data needed for CAT programs, as well as to identify how the data will be used, where it will be stored, and for how long.

Collectively, these five strategies are recommended to form a foundation upon which the other 30 CAT strategies can be built. These strategies naturally support TxDOT's TSMO program as they complement the TSMO goals and objectives discussed in Section 3. The next set of strategies in the CAT Strategic Plan are recommended to begin implementation in the near term (2-4 years), which corresponds to TxDOT's Statewide Transportation Improvement Program (STIP), and these comprise 17 individual strategies across all eight focus areas. The corresponding 15 TSMO near-term strategies are also shown in Table 6.

NEAR-TERM   MID-TERM   LONG-TERM

Table 6: CAT and TSMO Strategies Recommended for Near-Term Implementation

CAT Focus Area	CAT or TSMO Strategy #	Strategy Description
CAT Strategies		
Policy	**4**	Identify Regulatory Policies that may Impact CAT Implementation
	5	Develop Statewide Guidance for CAT Project Planning and Implementation
	6	Update Existing Design Manuals and Standards to Accommodate CAT Deployments
Fiscal Responsibility	**8**	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs
	9	Pursue Public-Private Partnerships for Technology Development and Deployment
	10	Support the Pursuit of Federal Grant Funding for CAT Projects
Collaboration	**13**	Expand TxDOT's Internal and External Conferences to Feature CAT
	14	Continue to Support and Expand Partnerships with Research Institutions, Academia, Industry and Peer Agencies
Infrastructure Readiness	**19**	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors
Systems Readiness	**25**	Update Existing Data Management Strategies to Address the Unique Challenges of CAT and Capitalize on CAT Data Opportunities
	26	Develop Common Data Standards and Influence their Widespread Adoption
	27	Expand Upon Efforts to Create an Information Portal for Sharing CAT Initiative Information
Multimodal	**28**	Enhance Visibility of Vulnerable Road Users in CAT Project Areas
Maintenance and Operations	**31**	Deploy CAT Projects that Address Common Operational Scenarios
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies
Procurement	**34**	Incorporate CAT Design, Construction, Operations and Maintenance into Procurement Rules and Policies

CAT Focus Area	CAT or TSMO Strategy #	Strategy Description
	35	Support Flexible and Agile Procurement Practices
TSMO Strategies		
	1	Develop Methodology to Allocate ITS/Signals O&M Funding to Align with TSMO Goals
	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
	6	Conduct Connected Roadway Classification System (CRSC) Analysis to Prepare for CAT
	8	Increase ITS Systems Support by TRF to the Districts to Improve Asset Uptime
	10	Develop Enhanced Traffic Signal System Implementation Plans
	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)
	14	Develop a Succession Plan for Essential Staff to Provide Continuity of Operations
	15	Develop and Maintain a Learning Management System (LMS)
	17	Realize the Full Potential of TxDOT's ITS Infrastructure During Pandemic Events
	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

The mid-term strategies are meant to correspond to the TxDOT United Transportation Program (UTP) and the Regional Transportation Plan 2040 (RTP). This timeframe includes 12 CAT strategies and 4 TSMO strategies, as shown in Table 7 below.

NEAR-TERM   **MID-TERM**   LONG-TERM

Table 7: CAT and TSMO Strategies Recommended for Mid-Term Implementation

Focus Area	CAT or TSMO Strategy #	Strategy Description
CAT Strategies		
Policy	7	Explore CAT Impacts on Border Crossing Policies and Procedures
Fiscal Responsibility	11 12	Support and Provide Internal Funding for CAT Initiatives Prepare for Changes in Revenue Streams Due to CAT Proliferation
Collaboration	15 16	Expand Workforce Capabilities with the Provision of CAT Training Perform Outreach to Promote Internal and External Acceptance of CAT Initiatives
Infrastructure Readiness	17 20 21 22 23	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas Build Communications Readiness into Roadway Construction Projects Support the Provision of Statewide Communications Availability Strategically Allocate Space for EV Charging Infrastructure Explore Design Options to Incorporate CAV Operations
Multimodal	29	Explore CAT Applications that Benefit Multimodal Travel
Maintenance and Operations	33	Identify CAT Impacts and Needs for Smart Work Zones
TSMO Strategies		
	2	Develop Statewide Standard Operating Procedures to Improve Operational Interoperability
	7	Develop AI/Machine Learning Applications that Address Common Operational Scenarios
	9	Develop and Implement Integrated Corridor Management along Applicable Strategic Corridors
	11	Implement Lonestar™ Enhancements

Finally, the long-term strategies target the Texas Transportation Plan 2050 (TTP), and there is one strategy for each of TSMO and CAT shown in Table 8 below

Table 8: CAT and TSMO Strategies Recommended for Long-Term Implementation

CAT Focus Area	CAT or TSMO Strategy #	Strategy Description
CAT Strategy		
Multimodal	**30**	Explore Next Generation Mobility Hub Concepts
TSMO Strategy		
	16	Apply Gamification Strategies as an Incentive to Continuously Improve Operational Performance

In the next section, we'll discuss some specific TSMO and CAT activities that can be implemented in a way that complements the strategies of each. The CAT Program Plan is currently under development and has already identified over 70 individual programs or projects to implement the 35 strategies.

3.2T   TSMO Strategies and Their Supporting CAT Strategies

As discussed previously, the relationship between the 20 TSMO and 35 CAT strategies can be viewed through their relationship to the underlying CMM assessments and by their recommended timeframe for initiation. Because the concepts of TSMO and CAT are complimentary, and the strategies developed for implementing a CAT program in Texas will support and enhance the strategies for implementing TSMO Strategies, we can also identify the CAT strategies that are likely to most directly support a specific TSMO strategy. This does not mean other strategies would not be supportive in some way, but that these identified CAT strategies are likely to more directly affect the implementation of the TSMO strategy.

Table 1 showed each TSMO strategy with its associated supporting CAT strategies in detail. The TSMO strategy #4 (Develop Emergency Response Plan to Improve Preparedness, Response and Recovery) is recommended to be implemented in the near-term timeframe and is supported by a number of CAT strategies as shown in Table 9 below, including their associated timeframes for implementation.

Table 9: CAT Strategies for Emergency Response Plan to Improve Preparedness, Response and Recovery

TSMO Strategy #4 - Develop Emergency Response Plan to Improve Preparedness, Response and Recovery			Near Term
CAT Strategies	**1**	Institutionalize TxDOT's CAT Program	Immediate
	18	Prepare Traffic Management System for CAT Readiness	Immediate
	19	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors	Near
	20	Build Communications Readiness into Roadway Construction Projects	Mid
	21	Support the Provision of Statewide Communications Availability	Mid
	29	Explore CAT Applications that Benefit Multimodal Travel	Mid
	31	Deploy CAT Projects that Address Common Operational Scenarios	Near
	32	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies	Near

There are two CAT strategies (**1 and 18**), which are recommended to be implemented immediately, three strategies (**19, 31, and 32**) recommended for the near-term, and three strategies (**20, 21, and 29**) recommended for a mid-term timeframe. The specific programs and project recommendations that will be developed as part of the CAT Program Plan will each be targeted at supporting an individual CAT strategy, but collectively, the programs developed under these eight CAT strategies will work to support this single TSMO strategy. Conversely, the programs and projects developed to support this TSMO strategy as part of TxDOT's broader TSMO program, will also enable the success of these underlying CAT strategies. Another TSMO strategy that incorporates many of these same CAT strategies is **strategy #17 (Realize the Full Potential of TxDOT's ITS Infrastructure During Pandemic Events).**

The **TSMO strategy #18 (Support Rural District Operations that have Limited Resources to Support TSMO Goals)** is also a near-term strategy and is supported by a number of CAT strategies (**#5, 6, 7, 9, 10, 15, 17, and 21**). Half of these are near-term and half are mid-term.

Table 10: CAT Strategies for Rural District Operations that have Limited Resources to Support TSMO Goals

TSMO Strategy #18 - Support Rural District Operations that have Limited Resources to Support TSMO Goals			Near Term
CAT Strategies	5	Develop Statewide Guidance for CAT Project Planning and Implementation	Near
	6	Update Existing Design Manuals and Standards to Accommodate CAT Deployments	Near
	7	Explore CAT Impacts on Border Crossing Policies and Procedures	Mid
	9	Pursue Public-Private Partnerships for Technology Development and Deployment	Near
	10	Support the Pursuit of Federal Grant Funding for CAT Projects	Near
	15	Expand Workforce Capabilities with the Provision of CAT Training	Mid
	17	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas	Mid
	21	Support the Provision of Statewide Communications Availability	Mid

4. Integrating CAT Programs into TSMO

The next major milestone to advance CAT efforts at TxDOT is the development of a Program Plan, which is currently underway. While the Strategic Plan focuses on high-level, forward-looking priorities, the Program Plan will serve as a work plan with specific operational initiatives recommended to achieve the goals of the CAT program. This will serve as a roadmap for strategy implementation, with initiatives recommended to achieve the strategies outlined in the CAT Strategic Plan. Having both a Strategic Plan and Program Plan will align CAT efforts across all TxDOT divisions, and the Program Plan will include specific actions recommended to achieve each strategy. The following topics are relevant to successfully integrating CAT and TSMO strategies, some of which will be covered in more detail in the CAT Program Plan.

4.1   CAT Project Prioritization Methodology

Evaluation criteria will be determined for proposed CAT projects that align with the goals of the CAT Program, deliver high value CAT projects and maximize benefits for the cost expended. A user-friendly methodology will be developed to help TxDOT prioritize CAT projects, based on those criteria, to optimize available funding. It will allow TxDOT to complete an "apples to apples" comparison between technology projects in a given district or across the state. For example, the CAT Program Plan is developing a CAT Project Prioritization Framework to identify the necessary evaluation criteria and the process for prioritizing proposed CAT projects. Part of this evaluation must take into account the technology readiness level (TRL)[1] of the proposed system and sub-components. Some proposed CAT projects may be evaluated to be "deployment ready", where others are "future deployment" and specific performance specifications should be developed regarding the CAT technology needed to support the system. As more CAT technology becomes commercialized, and its performance characteristics are better understood, the TRL of the component technologies and the system as a whole will increase, and thus the evaluation process that TxDOT uses will also change to accommodate the increased capability maturity of the industry.

Proposed projects that do not directly rely on the presence or function of a specific technology may not be concerned with technology TRLs, but will still be evaluated against CAT program goals as described briefly below:

- *Safety*: The project improves safety for the traveling public and helps achieve TxDOT's Road to Zero goal to achieve zero fatalities on roadways by 2050 and cut fatalities in half by 2035
- *Reliability*: The project improves overall system dependability for both people and freight
- *Mobility*: The project improves mobility and accessibility for all road users
- *Agility*: The project supports the agency's proactive approach to CAT technology deployment
- *Vitality*: The project provides a direct or indirect economic benefit to the State of Texas

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[1] FHWA Technology Readiness Level Guidebook https://www.fhwa.dot.gov/publications/research/ear/17047/17047.pdf

4.2   Performance Measures

Project evaluation performance measure guidance will be provided at a high level, and project-specific performance measures will be developed by stakeholder teams for each program or project initiated from a specific TSMO or CAT strategy. Performance measures should be structured to capture the goals of CAT and TSMO programs, such as safety, reliability, mobility, agility, and vitality. Specifically, the metrics of travel time reliability, incident clearance time, and asset up time were determined to be priority metrics established by TxDOT Leadership, and 16 additional operations metrics were identified to promote traffic management. These metrics will be similarly important for CAT programs. Since 2017, three Traffic Management System metrics have been tracked and reported monthly on Engineering Operations Dashboard in Tableau (a data visualization software application), and the data collected as a result of CAT technology deployments will contribute significantly to TxDOT's understanding of project performance.

4.3   Potential Funding Sources

One potential source of funding for implementing CAT programs that are complementary to TxDOT's TSMO programs is through grant opportunities. Grants should be pursued that include opportunities specific to the adoption, integration, and acceleration of CAT technology. Additionally, grants that may be focused on other goals that can be accomplished using CAT technology (e.g. safety, sustainability, or resilience objectives) will be identified.

New business models are also being explored across the nation as departments of transportation seek new revenue streams beyond traditional gas tax. One of these business models is mileage-based user fee, also called road-use charging (RUC). With the introduction of CAT technologies in both vehicles and in infrastructure, accurately tracking the road usage of a vehicle becomes relatively trivial, and systems should be developed to capitalize on this information. Similarly, these technologies are well-adapted for advanced tolling and congestion pricing transactions, which can be automated and secure.

CAT technology Original Equipment Manufacturers (OEM) have also shown an interest in developing data sharing agreements with IOOs, where a mutually beneficial arrangement can be made. This may not result directly in sources of revenue for TxDOT, but data sharing is a critical aspect for the effective implementation of both CAT and TSMO strategies. For example, the Smart Mobility Office of the City of Austin's Transportation Department negotiated successfully with micro-mobility (scooter) providers after they appeared in the city unannounced. The data sharing arrangement, in part, allowed the City of Austin to maintain control of the deployment of these devices across the city, and provided valuable insight into the movement of people who selected this mode choice. This type of insight can enable implementation of other initiatives more effectively, which in the case of TSMO and CAT programs, would result in cost savings during the implementation, and possibly additional revenue sources.

Many of the same federal grant programs that can be used for TSMO projects can also be used for CAT projects, including the Surface Transportation Block Grant program (STBG, formerly Surface Transportation Program), the Congestion Mitigation and Air Quality (CMAQ) program, the Highway Safety Improvement Program (HSIP), the National Highway Performance Program (NHPP), and the Surface Transportation Program (STP). Additionally, related to CAT projects that address modes of transportation such as transit, the Accelerating Innovative Mobility

(AIM) grants should also be considered. The Federal Transit Administration (FTA) has several discretionary or competitive grant programs such as AIM, which are targeted at innovation. These include:

- **Access and Mobility Partnership Grants**: This program provides competitive funding to support innovative capital projects for the transportation disadvantaged that will improve the coordination of transportation services and non-emergency medical transportation services.

- **Integrated Mobility Innovation:** FTA's Integrated Mobility Innovation (IMI) Program funds projects that demonstrate innovative and effective practices, partnerships and technologies to enhance public transportation effectiveness, increase efficiency, expand quality, promote safety and improve the traveler experience.

- **Public Transportation Innovation – 5312**: Provides funding to develop innovative products and services assisting transit agencies in better meeting the needs of their customers.

- **Transit Cooperative Research Program - 5312(i)**: Research program that develops near-term, practical solutions such as best practices, transit security guidelines, testing prototypes, and new planning and management tools.

- **Advanced Transportation & Congestion Management Technologies Deployment (ATCMTD)**: This program was established by the Fixing America's Surface Transportation (FAST) Act for the development of model deployment sites for the large-scale installation and operation of advanced transportation technologies. The FAST Act reauthorization is currently being addressed in the US Congress, and the program's details may change going forward.

The FAST Act also established the Surface Transportation System Funding Alternatives (STSFA) program and the Accelerated Innovation Deployment (AID) demonstration program. The STSFA program is focused on alternative funding mechanisms, such as user-based fees, for maintaining the long-term solvency of the Highway Trust Fund. The AID demonstration program, however, is focused on accelerating the implementation and adoption of innovation in the highway transportation system.

MPO activities that could support CAT programs include data collection, regional coordination efforts, and creation of subcommittees on CAT. MPOs may set aside funding for specific projects or programs, allows open competition, or a combination of both. Operational performance measures will enable CAT strategies to compete effectively for funding, similar to TSMO. The use of operational performance measures creates a system where TSMO projects may score highly enough to compete with other types of projects. Some MPOs use separate criteria for evaluating TSMO projects even when competing with other types of projects.

4.4 Potential Partnerships:

Both the Statewide TSMO Strategic Plan and the CAT Strategic Plan identify strategies related to creating and maintaining strong partnerships, both internal and external. TSMO addresses leveraging stakeholder partnerships in developing and executing inter-agency agreements, and Strategy #9 of the CAT Strategic Plan recommends pursuing Public-Private Partnerships (P3) for Technology Development and Deployment, which is recommended as a near-term strategy within the Fiscal Responsibility focus area. While each of the TxDOT Districts are developing individualized District TSMO Program Plans to address their specific needs, the

Statewide TSMO Strategic Plan provides the framework to establish consistency and interoperability. Similarly, the CAT Strategic and Program Plans are designed to provide consistency and interoperability across the state for the introduction of CAT technologies.

Additionally, it will be very important for TxDOT to develop partnerships with private industry involved in the development, testing, deployment, operations, and maintenance of CAT technologies. There are already a number of existing vehicle OEMs and new technology startups operating automated vehicles, many of them testing on Texas roadways, and establishing partnerships with these companies will be very beneficial, particularly if a data-sharing agreement can be reached.

4.5   Connected Roadway Classification System

TSMO strategy #6 recommends conducting an assessment of a major Texas corridor using the CRCS framework, as described in the National Cooperative Highway Research Program (NCHRP) 20-24(112) report prepared for the American Association of State Highway and Transportation Officials (AASHTO) and was released in February 2020. It is a process and set of tools that TxDOT can use to assess the readiness of their roadways specifically from the perspective of CAT while remaining technology agnostic. See Appendix A for an overview of the CRCS Assessment methodology using a case study for the 30 mile IH-30 corridor between Fort Worth and Dallas.

4.6   Infrastructure Integration

The CAT Strategic Plan has a specific Focus Area devoted to "Infrastructure Readiness", which contains the strategies 17-23; however, the CAT Strategic Plan has 21 individual strategies that target either digital or physical infrastructure CMM dimensions. These dimensions are combined in the TSMO Strategic Plan Update under "Systems and Technology, which contains strategies 6 through 11. So, a combined 26 strategies between the CAT and TSMO plans in some way target infrastructure readiness and integration. Some of these strategies, such as TSMO #6 and #7 are discussed separately in this document; however, there are many more strategies that will enable TxDOT to enhance their infrastructure readiness in order to incorporate CAT technologies, including TSMO #10 (Develop Enhanced Traffic Signal System Implementation Plans) and #11 (Implement Lonestar™ Enhancements), CAT #8, which recommends modernizing TxDOT's Asset Management Program, and CAT #24-27, which collectively target the focus area of System Readiness, and include strategies that will enhance TxDOT's data management plans and policies for CAT technologies.

One example for how the recommended CAT strategies support a specific TSMO strategy is TSMO strategy #10. This strategy is supported by CAT strategies #3, 5, 8, 18, 19, 23, and 32. The implementation timeframes for these strategies include immediate, near-term, and mid-term, and the specific projects and programs that will be developed under these strategies will target a variety of CMM dimensions across several focus areas to improve and enhance the systems and processes within TxDOT to integrate CAT technologies. An example program may include upgrades to existing traffic signal controllers to support enhanced cybersecurity protocols as well as V2I communications from connected vehicles. Another example is the creation of a centralized data exchange utilizing open data standards to ingest and process data from a variety of data sources, such as edge ITS and Internet of Things (IoT) devices, as well as connected vehicle Dedicated Short Range Communication (DSRC) or C-V2X devices.

5. Artificial Intelligence and Machine Learning Applications Using CAT Data

Strategy #7 in the TSMO Strategic Plan Update includes mid-term recommendations for Artificial Intelligence (AI) and Machine Learning (ML) applications that address common operational scenarios. This strategy is supported by **strategies 25, 26, 31, and 32** from the CAT Strategic Plan, which are all recommended to be initiated in the near-term timeframe.

AI and ML will become a critical factor in the implementation of CAT technologies, producing much more data than a traditional ITS device. Modern transportation systems already generate far more data than is currently being processed by existing systems. Systems that utilize AI and ML techniques have the potential to harness very large data sets from disparate sources to enable the effective implementation of both CAT and TSMO strategies. A number of application-specific use-cases are applicable including:

- Traffic Control

- Decentralized Congestion Mitigation

- Asset Detection and Management

- Smart Work Zone Management

- Wrong-Way Driver (WWD) Detection and Mitigation

- Cyber-security Threat Detection and Mitigation

5.1   Traffic Control

The efficient movement of people and goods within urban environments has always been a challenge. As the number of vehicles increase, so has their interactions, and collisions more frequent and more severe. Using AI/ML techniques to aid in traffic control could provide a decentralized approach to control of individual signals such that the system's performance is optimized. One enabling technology for this is edge-based computing, where the intersections would negotiate directly with their neighboring intersections, enabling them to exchange information directly regarding local conditions, and then make changes to signal timing. In this scenario, the data transmission requirements back to the TMC can be significantly reduced.

5.2   Decentralized Congestion Mitigation

The technologies and capabilities of a CAT system will fundamentally change how the transportation system operates, including the requirements placed on the system for data aggregation and management. Similarly, connected vehicles will have the ability to communicate with each other, as well as with a variety of infrastructure devices. The TMC then becomes akin to a central nervous system, absorbing information from many sources, but only acting on information that requires a targeted response (e.g., signal retiming), and this requires that the inflow of information can be ingested and acted upon relatively quickly. An example of this is the applications of priority and pre-emption where a vehicle requests priority through the intersection (a green phase more quickly than the current SPaT plan based on the lane of approach) or requests the SPaT cycle to immediately provide a green phase (pre-emption).

5.3   Asset Detection and Management

Techniques of AI and ML, by applying machine vision, could be applied to asset detection and management in using the movement of fleet vehicles to automatically identify and catalogue sign assets according to location, and to also detect indications of damage or excessive wear that might require repair or replacement. This would alleviate the burden on the IOO to devote vehicles and labor resources specifically for the purpose of locating and assessing sign assets, which may only be feasible every three to five years considering cost constraints. Mounting fleet vehicles with GPS-enabled camera systems and a means of storing compressed video data would enable this data to later be offloaded at the garage where the vehicle is stored, for example, and placed in a central database were automated AI and ML algorithms could process the data to detect new, missing, and damaged signs.

5.4   Smart Work Zone Management

Work zones are a great case for the application of AI and ML which can be applied to quickly detect the onset of congestion, a developing queue, or an incident that will require a rapid and effective incident response to clear the lanes as soon as possible. CAT technologies like connected and automated vehicles will contribute additional sensing and computing power to the existing, infrastructure-based ITS devices. With connectivity and automation, however, comes the threat of cyberattacks, which is addressed in a number of TSMO and CAT strategies.

5.5   Wrong-Way Driver Detection and Mitigation

There are a number of ways CAT technology can enable a wrong-way driver warning (WWD) system, including onboard knowledge of a connected or automated vehicle that it is traveling in the opposite direction as indicated in its map data, or through a camera-based detection of wrong-way signs. AI and ML techniques could be employed to eliminate false-positive detections, and to determine the mode and content of communication that will be most effective at protecting others on the roadway.

5.6   Cyber-security Threat Detection and Mitigation

As mentioned earlier, a number of the TSMO and CAT strategies deal with cyber security and enabling tools and processes, specifically TSMO strategy #5 and CAT strategies 3, 24, 25, and 26. TMCs will need the ability to detect and mitigate cyber threats and will require robust anomaly detection in order to discern the difference between normal and compromised system behavior. However, for a highly-connected system, such as CAT, the cyber threat can come from any device or system, and often AI and ML techniques are employed to detect anomalous network traffic or device behavior. The increasing connectivity among vehicles and other devices creates security risks with the potential for targeted disruption.

6.   Recommendations

This document supports the TxDOT TRF complimentary TSMO and CAT programs, which have each generated several strategic initiatives with the goal of improving safety and mobility for all modes of transportation throughout Texas and are detailed in their respective strategic plans. The 35 CAT strategies that have been identified support the 20 TSMO strategies in a variety of ways over a variety of timeframes, and this document has described these relationships.   These are described in the Executive Summary. Below are specific recommendations for how the CAT program can be leveraged to support TxDOT's TSMO efforts:

- Implement specific CAT programs and projects that will support the 15 near-term TSMO strategies as listed in the Executive Summary focusing on strategies that are recommended for immediate or near-term timeframes.

- Implement CAT programs and projects associated with CAT strategies that are listed as supporting strategies for several TSMO strategies (e.g. #1, #5, #18, #19, #20, #31, and #32).

- Engage with the technology industry for both connected and automated vehicles to understand the capability maturity and development roadmap of the technology, and to educate the industry on the challenges and opportunities from an IOO perspective.

Appendix A – Strategy Tables by CMM Dimension

Business Processes

Strategy #	TSMO/CAT	Focus Area	Strategy Description
1	TSMO	N/A	Develop Methodology to Allocate ITS/Signals O&M Funding to Align with TSMO Goals
2	TSMO	N/A	Develop Statewide Standard Operating Procedures to Improve Operational Interoperability
3	TSMO	N/A	Improve Procurement Processes to Support TSMO Program Objectives
4	TSMO	N/A	Develop Emergency Response Plan to Improve Preparedness, Response and Recovery
5	TSMO	N/A	Conduct Cybersecurity Vulnerability Analyses of IT Networks to Improve Resiliency
1	CAT	Policy	Institutionalize TxDOT's CAT Program
3	CAT	Policy	Implement Robust Security and Privacy Policies
4	CAT	Policy	Identify Regulatory Policies that May Impact CAT Implementation
5	CAT	Policy	Develop Statewide Guidance for CAT Project Planning and Implementation
6	CAT	Policy	Update Existing Design Manuals and Standards to Accommodate CAT Deployments
7	CAT	Policy	Explore CAT Impacts on Border Crossing Policies and Procedures
8	CAT	Fiscal Responsibility	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs
9	CAT	Fiscal Responsibility	Pursue Public-Private Partnerships for Technology Development and Deployment
10	CAT	Fiscal Responsibility	Support the Pursuit of Federal Grant Funding for CAT Projects
11	CAT	Fiscal Responsibility	Support and Provide Internal Funding for CAT Initiatives
12	CAT	Fiscal Responsibility	Prepare for Changes in Revenue Streams Due to CAT Proliferation
15	CAT	Collaboration	Expand Workforce Capabilities with the Provision of CAT Training
24	CAT	System Readiness	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies
25	CAT	System Readiness	Update Existing Data Management Strategies to Address the Unique Challenges of CAT and Capitalize on CAT Data Opportunities
26	CAT	System Readiness	Develop Common Data Standards and Influence their Widespread Adoption

Strategy #	TSMO/CAT	Focus Area	Strategy Description
31	CAT	Maintenance and Operations	Deploy CAT Projects that Address Common Operational Scenarios
32	CAT	Maintenance and Operations	Explore CAT-Enabled Innovative Traffic Operations and Management Strategies
33	CAT	Maintenance and Operations	Identify CAT Impacts and Needs for Smart Work Zones
34	CAT	Procurement	Incorporate CAT Design, Construction, Operations and Maintenance into Procurement Rules and Policies
35	CAT	Procurement	Support Flexible and Agile Procurement Practices

Systems and Technology (TSMO), Digital and Physical Infrastructure (CAT)

Strategy #	TSMO/CAT	Focus Area	Strategy Description
6	TSMO	N/A	Conduct Connected Roadway Classification System (CRCS) Analysis to Prepare for CAT
7	TSMO	N/A	Develop AI/Machine Learning Applications that Address Common Operational Scenarios
8	TSMO	N/A	Increase ITS Systems Support by TRF to the Districts to Improve Asset Uptime
9	TSMO	N/A	Develop and Implement Integrated Corridor Management along Applicable Strategic Corridors
10	TSMO	N/A	Develop Enhanced Traffic Signal System Implementation Plans
11	TSMO	N/A	Implement Lonestar™ Enhancements
5	CAT	Policy	Develop Statewide Guidance for CAT Project Planning and Implementation
8	CAT	Fiscal Responsibility	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs
9	CAT	Fiscal Responsibility	Pursue Public-Private Partnerships for Technology Development and Deployment
15	CAT	Collaboration	Expand Workforce Capabilities with the Provision of CAT Training
17	CAT	Infrastructure Readiness	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas
20	CAT	Infrastructure Readiness	Build Communications Readiness into Roadway Construction Projects
21	CAT	Infrastructure Readiness	Support the Provision of Statewide Communications Availability
29	CAT	Mode Choice	Explore CAT Applications that Benefit Multimodal Travel
30	CAT	Mode Choice	Explore Next Generation Mobility Hub Concepts

Strategy #	TSMO/CAT	Focus Area	Strategy Description
31	CAT	Maintenance and Operations	Deploy CAT Projects that Address Common Operational Scenarios
32	CAT	Maintenance and Operations	Integrate CAT into TSMO, Traffic Incident Management (TIM),and Traffic Management Center (TMC) Strategies and Operations
33	CAT	Maintenance and Operations	Identify CAT Impacts and Needs for Smart Work Zones
19	CAT (Phys)	Infrastructure Readiness	Provide Backhaul Communications for TxDOT Assets Along Priority Corridors
24	CAT (Phys)	System Readiness	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies
25	CAT (Phys)	System Readiness	Update Existing Data Management Strategies to Address the Unique Challenges of CAT and Capitalize on CAT Data Opportunities
26	CAT (Phys)	System Readiness	Develop Common Data Standards and Influence their Widespread Adoption
27	CAT (Phys)	System Readiness	Expand Upon Efforts to Create an Information Portal for Sharing CAT Initiative Information
18	CAT (Dig)	Infrastructure Readiness	Prepare Traffic Management System for CAT Readiness
22	CAT (Dig)	Infrastructure Readiness	Strategically Allocate Space for EV Charging Infrastructure
23	CAT (Dig)	Infrastructure Readiness	Explore Design Options to Incorporate CAV Operations
28	CAT (Dig)	Mode Choice	Enhance Visibility of Vulnerable Road Users

Performance Measurement

Strategy #	TSMO/CAT	Focus Area	Strategy Description
12	TSMO	N/A	Implement Performance Dashboards for Safety and Travel Reliability During Construction
13	TSMO	N/A	Apply Performance Measures to all Applicable Phases of Project's Life Cycle (Planning-Operations)
1	CAT	Policy	Institutionalize TxDOT's CAT Program
2	CAT	Policy	Coordinate Emerging Technology Planning Initiatives
5	CAT	Policy	Develop Statewide Guidance for CAT Project Planning and Implementation
31	CAT	Maintenance and Operations	Deploy CAT Projects that Address Common Operational Scenarios

32	CAT	Maintenance and Operations	Integrate CAT into TSMO, Traffic Incident Management (TIM),and Traffic Management Center (TMC) Strategies and Operations

Organization and Workforce (TSMO) + Culture (TSMO), Organization, Staffing, and Culture (CAT)

| Strategy #	TSMO/CAT	Focus Area	Strategy Description
14	TSMO (O&W)	N/A	Develop a Succession Plan for Essential Staff to Provide Continuity of Operations
15	TSMO (O&W)	N/A	Develop and Maintain a Learning Management System (LMS)
16	TSMO (Culture)	N/A	Apply Gamification Strategies as an Incentive to Continuously Improve Operational Performance
17	TSMO (Culture)	N/A	Realize the Full Potential of TxDOT's ITS Infrastructure During Pandemic Events
1	CAT	Policy	Institutionalize TxDOT's CAT Program
5	CAT	Policy	Develop Statewide Guidance for CAT Project Planning and Implementation
8	CAT	Fiscal Responsibility	Allocate Additional Budget for Modernizing TxDOT's Asset Management Program to Support CAT Technology Needs
11	CAT	Fiscal Responsibility	Support and Provide Internal Funding for CAT Initiatives
12	CAT	Fiscal Responsibility	Prepare for Changes in Revenue Streams Due to CAT Proliferation
15	CAT	Collaboration	Expand Workforce Capabilities with the Provision of CAT Training
16	CAT	Collaboration	Perform Outreach to Promote Internal and External Acceptance of CAT Initiatives
27	CAT	System Readiness	Expand Upon Efforts to Create an Information Portal for Sharing CAT Initiative Information

Collaboration

Strategy #	TSMO/CAT	Focus Area	Strategy Description
18	TSMO	N/A	Support Rural District Operations that have Limited Resources to Support TSMO Goals
19	TSMO	N/A	Strengthen TIM Teams Collaboration with Stakeholders to Safely Reduce Incident Clearance Times
20	TSMO	N/A	Develop Special Event Checklist to Apply TSMO Strategies
1	CAT	Policy	Institutionalize TxDOT's CAT Program
2	CAT	Policy	Coordinate Emerging Technology Planning Initiatives
3	CAT	Policy	Implement Robust Security and Privacy Policies
5	CAT	Policy	Develop Statewide Guidance for CAT Project Planning and Implementation
6	CAT	Policy	Update Existing Design Manuals and Standards to Accommodate CAT Deployments
7	CAT	Policy	Explore CAT Impacts on Border Crossing Policies and Procedures
9	CAT	Fiscal Responsibility	Pursue Public-Private Partnerships for Technology Development and Deployment
10	CAT	Fiscal Responsibility	Support the Pursuit of Federal Grant Funding for CAT Projects
13	CAT	Collaboration	Expand TxDOT's Internal and External Conferences to Feature CAT
14	CAT	Collaboration	Continue to Support and Expand Partnerships with Research Institutions, Academia, Industry and Peer Agencies
15	CAT	Collaboration	Expand Workforce Capabilities with the Provision of CAT Training
16	CAT	Collaboration	Perform Outreach to Promote Internal and External Acceptance of CAT Initiatives
17	CAT	Infrastructure Readiness	Continue and Expand CAT Demonstrations /Deployments and Establish Innovation Areas
21	CAT	Infrastructure Readiness	Support the Provision of Statewide Communications Availability
22	CAT	Infrastructure Readiness	Strategically Allocate Space for EV Charging Infrastructure
24	CAT	System Readiness	Identify and Prioritize Use Cases for CAT Data to Inform Data Management Plans and Policies
25	CAT	System Readiness	Update Existing Data Management Strategies to Address the Unique Challenges of CAT and Capitalize on CAT Data Opportunities
26	CAT	System Readiness	Develop Common Data Standards and Influence their Widespread Adoption

Strategy #	TSMO/CAT	Focus Area	Strategy Description
27	CAT	System Readiness	Expand Upon Efforts to Create an Information Portal for Sharing CAT Initiative Information
29	CAT	Mode Choice	Explore CAT Applications that Benefit Multimodal Travel
31	CAT	Maintenance and Operations	Deploy CAT Projects that Address Common Operational Scenarios
32	CAT	Maintenance and Operations	Integrate CAT into TSMO, Traffic Incident Management (TIM), and Traffic Management Center (TMC) Strategies and Operations

Appendix B - CRCS Assessment: Case Study IH-30 Summary Report

This CRCS assessment provides a CV and AV readiness analysis for the IH-30 corridor between Dallas and Ft. Worth, specifically a ~30-mile stretch of IH-30 between IH-820 and Texas-12 by applying the CRSC analysis framework. The CRSC methodology is described in the NCHRP 20-24(112) report prepared for the American Association of State Highway and Transportation Officials (AASHTO) and was released in February 2020. It is a process and set of tools that can be used to assess the readiness of the roadway, specifically from the perspective of CV/AV while remaining technology agnostic.
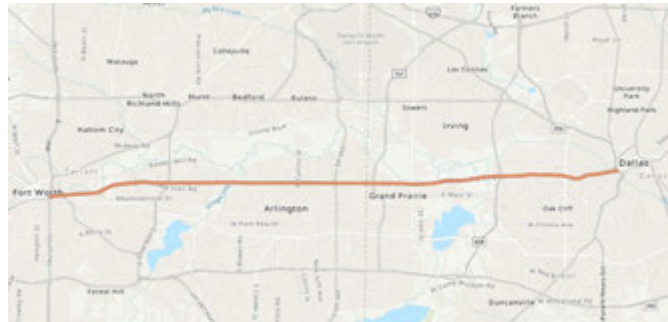
CRCS Study Corridor

The CRCS may be used for identifying CV/AV applications, exploring data exchange and open data needs, and communicating with the public and other stakeholders as to the readiness of a roadway system to support CV/AV applications. The purpose of the CRCS is to provide IOOs with a process and set of tools to assess the readiness of their roadways for the deployment of AV and CV applications, while remaining agnostic to specific technologies, across three different infrastructure approaches and four classification levels.

Infrastructure Approaches

- Talking to the road
    - Electronic communications between vehicles and the roadway

- Seeing the road
    - Infrastructure assets that are readable by vehicle-based sensors

- Simplifying the road
    - Design and operations for automated vehicles and their uses

Classification Levels

- Needs upgrade and maintenance
    - Design or functionality that does not meet existing guidance for future technology accommodation

- Meets current best practices
    - Meets existing guidance for future technology accommodation

- Meets emerging market (1-5 years)

- — Design or functionality supporting early adoption of AV/CV applications
- Meets next decade market (10 years)
  - — Design or functionality supporting AV/CV applications

TxDOT has been expending considerable effort and funds to develop corridor evaluation and prioritization tools over the past several years, which have focused on traditional aspects of roadway design and maintenance, such as the need for road and bridge repair, and capacity enhancements to alleviate congestion. However, they have not been designed to evaluate the readiness of the corridor for CAT technologies, or the impact these technologies will have on the roadway in terms of safety and mobility. The CRCS framework could be integrated into these existing tools as a "layer", or it could be performed separately.

Study Goal

The goal of the CRCS is to provide IOOs with a process and set of tools to assess the readiness of their roadways for the deployment of AV and CV technologies and applications, while remaining agnostic to specific technologies, across three different infrastructure approaches and four classification levels. The results of the assessment lead to specific recommendations for improving the roadway readiness for the implementation of AV and CV technologies. Additionally, the goal of this assessment was to develop the CRCS framework further and to apply it to a corridor in Texas that may be the right candidate corridor for the deployment of CV and AV technologies and applications.

Study Purpose

The purpose of the CRCS, in general, is to enable IOOs to evaluate the readiness of a roadway, corridor, or region for deployment and integration of AV and CV technologies and applications. The results of such an assessment can be used for a variety of purposes, such as:

- Project planning and prioritization
- Identifying CV/AV infrastructure deployments in support of emerging Vehicle-to Infrastructure (V2I) applications
- Exploring data exchange and open data needs
- Communication with the public and other stakeholders

The purpose of this assessment was to apply the new CRCS framework as a test case to flesh out specific methods and tools for performing this type of work and then to apply this technique to a corridor in Texas. The results from this project will not only illustrate the readiness level of the study corridor for AV and CV technologies and applications but will provide valuable insight into the methods and tools needed for performing future CRCS assessments throughout the State.

Corridor Evaluation using CRCS Capability Matrix

AECOM developed a method for evaluation that includes qualitative and quantitative assessments, resulting in numerical value between 0 and 5 for each of the three infrastructure approaches. This method enabled the team to evaluate the readiness of the roadway along a continuum, rather than constraining it to distinct classifications, as some aspects of each of the infrastructure approaches for a given roadway can fall in one classification level while other aspects are characteristic of another level. As the information-gathering phase was underway, a

Level 0 ---->	Roadway presents serious challenges to readiness for CVs or AVs
Level 1 ---->	Roadway has significant restrictions on the deployment of CVs or AVs
Level 2 ---->	Roadway is moderately ready for CVs or AVs, but still poses significant challenges for effective deployment
Level 3 ---->	Roadway is moderately ready for CVs or AVs, but may still pose challenges for effective deployment
Level 4 ---->	Roadway is highly ready for CVs or AVs, and the remaining challenges are relatively minor
Level 5 ---->	Roadway is highly ready for CVs or AVs with few or no remaining challenges for deployment

CRCS level description

spreadsheet-based tool was developed to perform the CRCS evaluation and was developed using a mix of guidance from the NCHRP project report and the expertise and experience of AECOM's team of CV/AV subject matter experts. The evaluation technique and spreadsheet-based tool was developed as a proof-of-concept, as the CRCS framework is new and provides flexibility in its implementation.

List of Potential Data Sources

Data Type	Data Source
Crash Data	CRIS (https://cris.dot.state.tx.us/public/Query/app/welcome)
ITS Devices	Lonestar™
Fiber Map	Southwest Research Insititute
Current Construction	Drive Texas (https://drivetexas.org)
AT&T Coverage Map	https://www.att.com/maps/wireless-coverage.html
Verizon Coverage Map	https://www.verizon.com/featured/our-network/#maps
T-Mobile Coverage Map	https://www.t-mobile.com/coverage/coverage-map
Complexity Map	AECOM

Each of the infrastructure approach tabs are constructed per the previous discussion and are organized according to primary categories and secondary attributes, which are then individually evaluated. The full list of categories and attributes are listed below:

The evaluation continues with the user evaluating the readiness levels for each attribute, and then the scores are combined to create a single number for the infrastructure approach, These values from each of the infrastructure approach tabs are imported into the Results tab, and then they are rescaled to a value from 0 to 5 and displayed visually. The team settled on a six-level assessment scale, with the following descriptions:

The lessons learned through this type of exercise will be valuable for establishing a method and analytic tool for conducting this type of assessment, and also provides potential areas for improvement in order to perform assessments on other strategic corridors across the state.