TxDOT Statewide Systems Engineering

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Prepared By

AECOM Imagine it. Delivered.

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DOCUMENT CONTROL

Date	Version	Description
8-13-20	1.0	First draft for review (Prepared by AECOM)
12-14-20	2.0	Addresses TxDOT review comments
1-15-21	3.0	Addresses AECOM Review Comments
2-08-21	3.1	Formatting to TxDOT Template

List of Acronyms

Acronym	Definition
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation
AVL	Automated Vehicle Location
CCTV	Closed Circuit Camera Television
COTS	Commercial Off The Shelf
CNA	Contact Notification Application
CMM	Capability Maturity Model
ConOps	Concept of Operations
CSA	Combined Statistical Areas
DMS	Dynamic Message Sign
DOT	Department of Transportation
EM	Event Management
FHWA	Federal Highway Administration
ICM	Integrated Corridor Management
ITS	Intelligent Transportation Systems
MMSA	Metropolitan and Micropolitan Statistical Areas
MPO	Metropolitan Planning Organization
O&M	Operations & Maintenance
PSEMP	Project Systems Engineering Management Plan
RVTM	Requirements Verification Traceability Matrix
SAA	System Administration Application
SEA	Systems Engineering Analysis
TMC	Transportation Management Center
TMS	Traffic Management System
TRF	Traffic Safety Division (Central Office)
TSMO	Transportation Systems Management & Operations
TSS	Transportation Sensor System
TTA	Travel Times Application
TTP	Texas Transportation Plan
TxDOT	Texas Department of Transportation

Executive Summary

In recent years, Transportation Systems Management & Operations (TSMO) has played an important role in managing, maintaining, and improving the safety and efficiency of existing roadway infrastructure at the national, state, and regional levels. The Texas Department of Transportation (TxDOT) has adopted a TSMO vision and mission statement as presented below.

- 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.

In support of the above TSMO vision and mission statements, the initial TxDOT “Statewide TSMO Strategic Plan” was issued on August 21, 2017 then updated during May 2020.

What is TSMO?

The Federal Highway Administration (FHWA) defines TSMO 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.” Essentially, TSMO is a set of strategies that focus on the operational improvements that can maintain and even restore the performance of the existing transportation system before extra capacity is needed.

TSMO is a shift in how the management of transportation systems is approached to optimize existing infrastructure and focus on the end user. TSMO encourages all stakeholders to consider operations throughout the project development process and prioritize the quality of life of the road user along with the safety and maintenance of a facility. It requires a collaborative effort among the various divisions and districts within TxDOT as well as through multiple agencies and regional partnerships to ensure that mobility and efficiency is upheld throughout the project life cycle. Strategies address both recurring and non-recurring congestion to improve system reliability, while still preserving capacity when possible.

What is Systems Engineering?

Systems engineering is a recommended approach in planning, designing, implementing, testing, operating, and maintaining an Intelligent Transportation System (ITS) project throughout its useful life. Similar to TSMO, it requires a collaborative effort among stakeholders from various divisions and districts within TxDOT and other partner agencies to ensure that an ITS project meets mobility and efficiency goals throughout the project's life cycle.

The systems engineering process begins with development and implementation of an ITS architecture and continues by outlining the steps and level of detail of each phase of project deployment, from high-level tasks such as establishing the Concept of Operations to very detailed component design, installation, and testing. The purpose of the systems engineering process is to ensure that a well-planned foundation is in place and then to affirm the requirements of an ITS system. Please refer to Section 2.0 for more details on the systems engineering process.

What is an ITS Architecture?

An ITS architecture is a planning-level framework for ITS project planning, programming, and implementation and provides a regional overview on how an ITS project relates to other ITS projects and technologies within that region. Prior to the beginning of an ITS project, the identification of the project within an ITS Architecture can define the basic scope of a project within a regional context. Opportunities for integration with other existing or planned ITS systems can be identified for further definition within a Concept of Operations.

The architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) provides a common framework for planning, defining, and integrating ITS. It is a mature product that reflects the contributions of a broad cross-section of the ITS community (e.g., transportation practitioners, systems engineers, system developers, technology specialists, consultants).
ARC-IT is a reference architecture: it provides a common basis for planners and engineers with differing concerns to conceive, design and implement systems using a common language as a basis for delivering ITS, but does not mandate any particular implementation. ARC-IT includes artifacts that answer concerns relevant to a large variety of stakeholders, and provides tools intended for transportation planners, regional architects and systems engineers to conceive of and develop regional architectures, and scope and develop projects. More info about ARC-IT can be found at https://local.iteris.com/arc-it/.

What is a Concept of Operations?

A Concept of Operations is a high-level description of what the major system capabilities will be, and it should be written such that people with a wide range of technical backgrounds may easily understand it. The Concept of Operations attempts to answer the Who, What, When, Where, Why, and How questions for the system in general terms as shown in Figure 1.

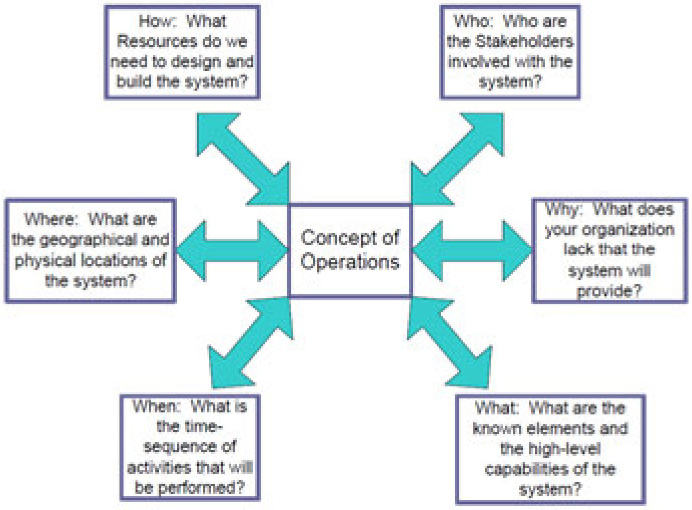

Figure 1: Concept of Operations

What TSMO Strategies can be Developed for Systems Engineering?

To improve TSMO capabilities among the districts and Texas as a whole, it is important to have a performance-based planning framework to follow. The six dimensions of capability that define the Capability Maturity Model (CMM) offers such a framework. The CMM process helps agencies identify strengths, weaknesses, and next steps for improvement. The six capability dimensions are: business processes, systems and technology, performance measurement, organization and workforce, culture and collaboration. The CMM process was applied by conducting workshops with TxDOT leadership at the central office level based on several operational scenarios. The results of the CMM workshops provided input in identifying TSMO strategies to consider in advancing the maturity level to improve the effectiveness in operating and managing the statewide transportation system.

Recommendations

TSMO strategies include a broad range of solutions to address how integrated strategies may be implemented in a coordinated manner. Table 1 summarizes these TSMO strategies related to Systems Engineering that are further detailed in Section 6.

Table 1: TSMO Systems Engineering Strategies

Recommended Strategies
Develop Systems Engineering Review Form to ensure that the systems engineering analysis meets the minimum requirements as defined in CRF 940.11
Establish Statewide Standards on Use of Systems Engineering by Districts
Develop Statewide Systems Engineering Management Plan for Districts
Develop Statewide Template for Other Systems Engineering Documentation
Review District ITS Architectures and Consolidate into Regional ITS Architectures for Multiple Districts
Develop Statewide Template for Concept of Operations Documents

1.0 Introduction

The International Council on Systems Engineering defines systems engineering as an interdisciplinary approach that focuses on defining needs and required functionality early in the project development cycle, documenting requirements, and then proceeding with design and system validation, while considering the problem that the system is addressing.

In relation to ITS, systems engineering is a recommended approach in planning, designing, implementing, testing, operation, and maintenance of ITS projects throughout their useful life. Similar to TSMO, it requires a collaborative effort among stakeholders from various divisions and districts within TxDOT and other partner agencies to ensure that an ITS project meets mobility and efficiency goals throughout the project life cycle.

The systems engineering process begins with the development and implementation of an ITS architecture and continues by outlining the steps and level of detail of each phase of project deployment, from high-level tasks such as establishing the Concept of Operations to very detailed component design, installation, and testing. The purpose of the systems engineering process is to ensure that a well-planned foundation is in place and then to affirm the requirements of an ITS system.

Figure 2 below illustrates the systems engineering process and the overall steps involved as a V-diagram from project inception on the left side, to the technology system end of life on the right side. Further definition of these steps is provided in the following sections of this chapter.

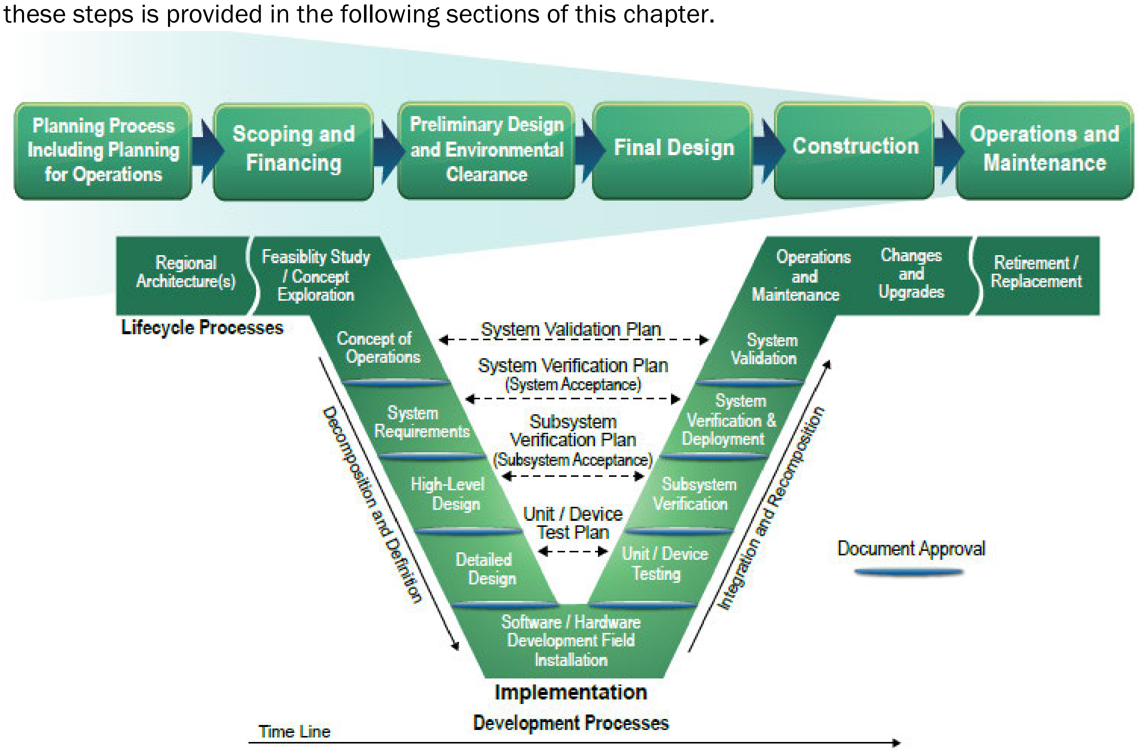

Figure 2: Systems Engineering Process V Diagram

FHWA has also realized the benefit of using Systems Engineering Analysis (SEA) on ITS projects and, since 2001, has required that a SEA be performed on all ITS projects funded through the Highway Trust Fund. Given the diversity in ITS projects, federal regulations require the SEA be on a scale commensurate with the project scope. As a result, this provides state and local agencies flexibility in the extent of how they conduct a SEA. The following sections provide guidance to address the following main challenges:

- **Systems Engineering** – Provides further definition of the steps involved in the Systems Engineering process and the overall benefits of the process, including best practices for application towards ITS deployments.
- **Planning for ITS System Expansion and Upgrades** – Provides an overview of the ITS coverage in the state of Texas and the coordination between TxDOT districts with respect to ITS operations and maintenance. Recommends TSMO strategies for how Systems Engineering can be implemented.
- **ITS Architectures** – Provides an overview of ITS Architecture development, including benefits that can be realized and requirements to consider. It also includes best practices for how other states have implemented statewide ITS Architectures and provides a TSMO strategy for how TxDOT can revise its approach to district-level ITS architectures to standardize practices across the state.
- **Concept of Operations** -- Provides an overview of Concepts of Operations, including benefits that can be realized and guidance from the FHWA on use with ITS projects. It provides best practices for how other states have developed Concepts of Operations and a TSMO strategy for establishing consistency across TxDOT Districts in its application.

2.0 Systems Engineering

Application of the systems engineering process to ITS projects reduces the risk of schedule and cost overruns and increases the likelihood that the implementation will meet the needs of all system users. Other benefits to the application of the systems engineering process include:

- **Improved stakeholder participation** - Identifying agencies that will play a role in the operation and maintenance and including them in the review process of project documentation will improve their participation in the project planning and design phases of the project.
- **More adaptable, resilient systems** - The use of ITS standards defined in the system requirements phase allow for field systems to adapt to changes in central software that configure and control those systems.
- **Verified functionality and fewer defects** - System verification of the requirements defined in the design phase will verify that the system operates as designed and lead to fewer system defects during operations.
- **Higher level of reuse from one project to the next** - As the practice of systems engineering is utilized, the process can be applied to more projects and lead to a consistent application over time.
- **Better documentation** - The use of systems engineering documentation provides a structure to identify key project information that can be understood by project planners, designers, and oversight personnel that can perform system verification activities.

In terms of project cost savings, application of systems engineering can significantly reduce the size and potential for cost overruns. Figure 3 illustrates the phases of the process at which project errors in planning and design can be addressed and the concept of how project implementation costs can be reduced. Identifying project errors at an early phase in the project can be exponentially less costly to address than it would be to address the issues while the project is in the construction phase.

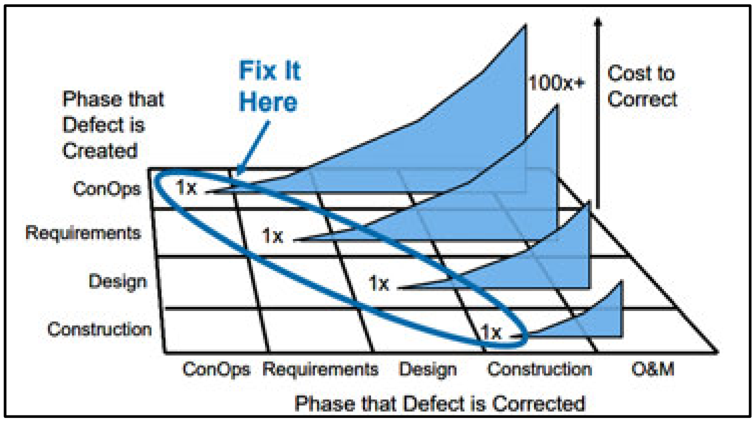

Figure 3: Illustration of Changes to Projects at Phases of Systems Engineering Process[1]

[1] Systems Engineering for ITS. FHWA, January 2007. https://ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf

2.1 Application to ITS Deployments

FHWA has required systems engineering analysis for all ITS projects using federal funds according to the Final Rule on Architecture and Standards Conformity. FHWA provides a listing of resources available to agencies for going through the planning and implementation phases of the systems engineering process. These phases that are all identified within the systems engineering V-Diagram discussed in more detail in Section 3.

TSMO includes a broad range of strategies in which ITS systems and technologies can be applied. Listed below are several of the operations strategies that have been applied across the country and that have made substantial positive impacts on the safety, mobility and reliability of the surface transportation network.

- Work Zone Management
- Traffic Incident Management
- Service Patrols
- Special Event Management
- Road Weather Management
- Transit Management
- Freight Management
- Traffic Signal Coordination
- Traveler Information
- Ramp Management
- Managed Lanes
- Active Traffic Management
- Integrated Corridor Management
- Rural Emergency Management

These strategies, in which ITS and traffic signals play a major role, are most effective when they are considered in early stages of the project development process, sustained over time with dedicated funding, and optimized via coordination among transportation agencies in the districts. Some TSMO strategies have already been deployed or are currently being researched for use in various parts of the state.

These strategies are relatively low in cost compared to adding capacity, can be implemented in two to three years, and yield relatively high benefit-cost ratios. Specifically, these benefits include savings in travel time and delay; improves reliability; decreases vehicle operating costs; and reduces the probability of primary and secondary crashes. A methodology for conducting benefit cost analyses for TSMO projects is included in the United States Department of Transportation (USDOT) publication TSMO Benefit Cost Analysis Compendium, July 2015.

While TSMO can be very beneficial to metro and urban areas, there is also a need for TSMO in rural areas. These types of TSMO projects include minor operational improvements, also known as low-cost enhancements, which are defined as small, low-cost projects that can be implemented quickly to improve operational safety or reduce congestion on the highway system. Such low-cost enhancement strategies include improvements in signage, pavement markings, and safety enhancements. Even if ITS projects and technologies are implemented without federal funding, application of the systems engineering process to all ITS projects at the state level is recommended given the noted benefits.

2.2 System Coverage of ITS in Texas

TxDOT Districts throughout the state have deployed ITS technologies for various applications along TxDOT roadways to achieve transportation goals and objectives that are aligned with the TSMO operations strategies previously identified. A total of 24 out of 25 TxDOT Districts also use a common ITS device management software known as Lonestar™ to control and configure these ITS technologies and applications (Lufkin is the only district that does not use the software). The most common types of ITS applications managed by TxDOT Districts through Lonestar™ are the following:

- **Closed Circuit Television (CCTV)** – Displays live camera video and images of TxDOT roadways.
- **Dynamic Message Signs (DMS)** – Presents traveler information on roadway incidents and travel times to the general public along TxDOT roadways.
- **System Administration Application (SAA)** – Application that allows for administrative control and configuration of CCTV and DMS technologies.

There are multiple other applications within the Lonestar™ central management software that can be utilized to control and configure ITS devices in addressing TSMO operations strategies. Metro districts within the state - such as Austin, Dallas, Fort Worth, Houston, and San Antonio - use more of these applications given greater needs for transportation management than urban and rural districts in the state. These applications used by Metro districts include the following:

- **Automated Vehicle Location (AVL)** – Presents a map-based view of TxDOT vehicles operating along roadways to provide roadside assistance and other services to travelers.
- **Contact Notification Application (CNA)** – Application that notifies a group of contacts regarding a transportation incident that requires a group response.
- **Event Management (EM)** – Application that allows TxDOT staff to automatically schedule event-based operations of ITS devices, such as specific message displays on DMS.
- **Travel Times Application (TTA)** – Presents estimated travel times to a destination along multiple TxDOT roadways so that travelers can determine the most appropriate route.
- **Transportation Sensor Subsystem (TSS)** – Displays traffic volumes along TxDOT roadways.

2.3 Planning for System Expansion and Upgrades

The Lonestar™ central management software is capable of supporting multiple types of transportation-related applications for TxDOT districts throughout the state. The underlying platform on which the software was built for TxDOT can support other applications as well if future needs arise related to specific TSMO Operations Strategies. Furthermore, the platform is also utilized by other states, including Florida and several other states, which allows for applications developed in those states to be added into the Lonestar™ central software as needed.

TxDOT is currently assessing operational usage of Lonestar™ by districts throughout the state to understand what types of improvements can be made that would enable a greater usage of the software. In April 2020, an anonymous on-line survey was conducted by TxDOT, to gather information from transportation management center (TMC) operators about existing operational tools. A total of 24 (out of 40) TMC operations staff responded to the survey to provide insight into their operational needs. This effort, in addition to operator interviews, will help TxDOT address these needs to develop and enact a vision for future operational tools. Table 2 presents preliminary findings of the survey.

Table 2: LonestarTM ATMS Software Survey Findings

Strengths	Weaknesses	Suggested Improvements
Easy to use with good mapping interface	Frequent crashes, upgrades don't always fix issues in a timely manner	More control over remote CCTV access between metro & rural areas
CCTV easy to use and provides snapshot images in other districts	CCTVs inability to view all roads and affected traffic lanes	Improved mapping interface
CCTV ability to view incidents in real time	Inability to download data and generate operator specific reports	Ability to view older reports and run individual reports on operators
Fast connection to DMS and quick confirmation of posted messages	Inability to operate CCTVs remotely or edit device from rural districts	Real time traffic information for better incident management.
Easy to view and coordinate events with TMC operator accountability	User interfaces are not consistent across all subsystems/applications	Develop predictive and real time analysis for mitigating incidents

In addition, TxDOT is working on consolidating district Lonestar™ deployments into a single cloud-based system.

3.0 Planning for ITS System Expansions and Upgrades

Table 3 presents the key activities to be performed during the systems engineering process.

Table 3: Overview of Key Systems Engineering Activities for ITS Projects

Process Steps	Description of Key Activities
Regional ITS Architecture	1) Identify of the regional stakeholders. 2] Build consensus for the purpose of information sharing and long-term O&M.
Feasibility Study / Concept Exploration	1) Perform an initial feasibility & benefits analysis. This results in a business case and specific cost benefit analyses for alternative project concepts. 2) Develop a needs assessment for the ITS project which can formally define the problem and help shape the goals, objectives, and vision of the project.
Concept of Operations	1) Document how the ITS project will operate and how it will meet the needs of project stakeholders through operational scenarios. 2) Refine the problem definition, needs, goals, expectations, and stakeholders. 3) Develop System Validation Plan for future evaluation of needs and objectives.
System Requirements	1) Define requirements on what the system will do, how well it is to perform, and under what conditions the system will operate. 2) Develop a Requirements Verification Traceability Matrix (RVTM) for system testing.
High-Level Design	1) Identify and evaluate internal and external system interfaces with other project stakeholders through project design diagrams. 2) Evaluate industry standards and perform a preliminary design review.
Detailed Design	1) Design how the individual system components will be built through further identification of component specifications. 2) Evaluate commercial off-the-shelf [COTS] hardware and software products against system requirements.
System Development / Field Installation	1) Hardware and software fabrication and procurement of COTS components. 2) Develop component test procedures for how the system will meet system design.
Unit / Device Testing	1) Perform unit testing against system requirements.
Subsystem / System Verification	1) Perform subsystem testing per the RVTM developed earlier. 2) Perform overall end-to-end system verification per the RVTM to verify all project and system requirements.
System Validation	1) Perform System Validation activities per the RVTM developed earlier to validate whether needs and objectives have been met by the systems.
Operations and Maintenance	1) Perform operations and maintenance of systems. 2) Perform system upgrades and changes as needed until system retirement.

3.1 Use of Systems Engineering Process by TxDOT Districts on ITS Projects

Given the previously stated benefits and cost savings that can result from the use of systems engineering processes in ITS projects, it is recommended that TxDOT encourage districts to apply the processes described in Table 4 to ITS projects throughout the state. This can include ITS projects and applications that integrate with the Lonestar™ central management software, as well as other ITS projects that address the various TSMO Operations Strategies previously identified.

As ITS projects will vary in size and complexity between metro, urban, and rural districts, application of the systems engineering processes will also vary in terms of the amount of required documentation. TxDOT will need to consider how state-level guidance on the use of systems engineering can be applied to different sizes of ITS projects deployed across different districts. For example, small scale ITS projects that plans to integrate new ITS devices, such as CCTV cameras or DMS, with an existing software package, may require less documentation than larger scale ITS projects that integrate multiple planned systems to be operated by multiple different stakeholders.

Further definition will need to be provided as to how much systems engineering documentation is required for various sizes of ITS projects. Establishing a process of applying Systems Engineering to all ITS projects can yield the types of cost savings and benefits for TxDOT over the long term.

3.2 Project Systems Engineering Management Plans for TxDOT Districts

For complex ITS projects that involve multiple planned systems to be operated by project stakeholders, development of a Project Systems Engineering Management Plan (PSEMP) is recommended to outline how the steps of the Systems Engineering will be applied.

The PSEMP details the systems engineering processes to be used throughout the ITS project and provides detailed information on the processes to be used. Given the level of detail needed in a PSEMP, it is often drafted at two different stages. Agency project management staff should develop a first draft with sufficient detail to identify the needed tasks and any important project constraints for review by a system designer. An updated draft is then prepared by the project design team that will perform the subsequent tasks outlined in the PSEMP, and the draft is updated to include system requirements and details on how the requirements will be tested and verified.[2]

Development of a PSEMP template document that can be utilized by TxDOT districts is recommended as a TSMO strategy. Utilizing a template PSEMP for complex ITS projects can yield the types of cost savings and benefits for TxDOT over the long term.

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[2] USDOT, FHWA. https://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_2.cfm

3.3 *Additional Systems Engineering Document Templates for TxDOT Districts*

In order to foster adoption of the steps of the systems engineering process, it is recommended that document templates be developed for use by TxDOT districts throughout the state. This can establish a consistent application of the systems engineering process by all TxDOT districts.

Document templates can be designed in Microsoft Word with use of TxDOT's approved logo and document formatting practices. These documents can be structured by TxDOT so that all the appropriate sections and sub-sections are included within the template. TxDOT districts and their project teams can then download the most recent version of the template documents for use at various phases of the systems engineering process.

This process of developing document templates has been followed by other state Department of Transportations (DOT) to achieve consistency across state districts. The Florida DOT maintains a website hosting document templates that can be downloaded for use in following the phases of the systems engineering process. This site is available for reference at: https://www.fdot.gov/traffic/its/projects-deploy/semp.shtm.

The development of additional systems engineering template documents that can be utilized by TxDOT districts is a recommended TSMO strategy. Utilizing these templates for all types of ITS projects can yield the types of cost savings and benefits for TxDOT over the long term.

4.0 ITS Architecture

An ITS architecture describes the "big picture" for ITS deployment in terms of individual components (i.e. subsystems) that will perform the functions necessary to deliver the desired needs. It describes what is to be deployed but not how those systems are to be deployed. An ITS architecture defines the components and subsystems that must interface with each other, the functions to be performed by those subsystems and the data flows among those subsystems.

An ITS architecture also serves as a roadmap for transportation systems integration. The architecture is developed through a cooperative effort by the region's transportation agencies, covering all modes and all roads in the region. Specifically, an ITS architecture has the following features:

- Represents a shared vision of how each agency's systems will work together in the future, sharing information and resources to provide a safer, more efficient, and more effective transportation system for travelers within the region.
- Provides an overarching framework that spans all of the region's transportation organizations and individual transportation projects.
- Using the architecture, each transportation project can be viewed as an element of the overall transportation system, providing visibility into the relationship between individual transportation projects and ways to cost-effectively build an integrated transportation system over time.

4.1 Relation to Statewide and District TSMO Program Plans

The Statewide TSMO Strategic Plan provides a TxDOT-statewide vision and strategy for implementing TSMO strategies, and a framework for TxDOT districts to conduct TSMO program planning. The statewide plan defines processes and agreements to conduct TSMO consistently across the state, and identifies the roles of central office and the districts for implementation.

District-level TSMO program plans provide details with specific steps and responsibilities for institutionalizing TSMO within the district. These plans define the goals, resources, performance measures, and institutional arrangements that will enhance transportation operations within each district. The plans may also interconnect with other district program plans as adjacent districts may have the same mobility needs, formal processes, or shared corridors.

District ITS Implementation Plans are each determined based on the district's needs and identify district- or corridor-specific mobility strategies to be implemented, including the operational procedures, roles, and responsibilities required for implementation. These plans will vary among districts because they are built on specific regional or corridor needs and challenges.

A District level ITS architecture can build upon the ITS Implementation Plan by providing a structured way to translate operational objectives and strategies into an interconnected set of ITS projects. This identifies the planning objectives and strategies that are supported by the districtwide ITS architecture.

4.2 Regional ITS Architecture Content

Regional ITS architectures developed for TxDOT districts contain the following information related to ITS projects that are defined within their respective districts:

- **Stakeholders** - Includes a diverse set of stakeholders encompassing traffic, public safety, and many other operating agencies at local, state and national levels. It includes both public and private sectors and spans the organizations that manage, support, or are impacted by the surface transportation system, with particular focus on agencies that operate transportation systems within the region.
- **Inventory** - Represents a list of all existing and planned "elements", which are ITS systems in a region as well as non-ITS systems that provide information to or obtain information from the systems. Each stakeholder agency, company, or group owns, operates, maintains or plans ITS systems in the region.
- **Service Packages** - Represents the transportation services that are important in the region and their deployment status. A service package collects several different ITS elements from the inventory and indicates their general functions and how information flows to other ITS elements as part of the service.
- **Operations Concept** - Documents each stakeholder's current and future roles and responsibilities in the operation of a regional ITS systems. The operational concept documents these roles and responsibilities across a range of transportation services.
- **Requirements** - Functional requirements for each ITS element can be defined based on the services and functions to be performed.
- `**Interfaces** - A primary purpose of the Regional ITS Architecture is to identify the integration opportunities among transportation systems (the "ITS elements") in the region. Every interface for the region can be defined in a Regional ITS Architecture and flows between ITS elements can be defined. An example of a Context Diagram illustrating operational linkages between ITS elements is presented in Figure 4. The diagram depicts the sharing of traffic images

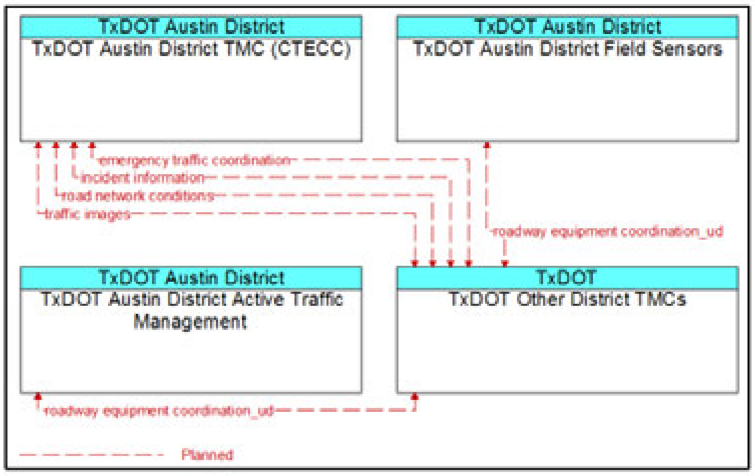

Figure 4: Example ITS Architecture Flow Diagram (Austin District)

generated by CCTV cameras as well as information on road network conditions, incidents, and emergency traffic coordination.

- **Standards** - Standards are an important tool that allow efficient implementation of the Regional ITS Architecture over time. Standards facilitate deployment of interoperable systems at local, regional and national levels without impeding innovation as technology advances, vendors change, and new applications evolve.
- **Agreements**: Agreements provide the institutional underpinnings for the technical integration identified in the Regional ITS Architecture.
- **Projects**: Individual ITS projects for the region can be also be defined by selecting a sub-set of ITS elements and services that are desired to be performed as part of the project. A recommended time frame for implementation and a brief project description can be identified.

4.3 Regional ITS Architectures in Texas

TxDOT districts throughout the state developed their own regional ITS architectures and deployment plans beginning in 2003. A total of 23 districts each contracted with various consulting firms to develop Regional ITS architectures over time with completion dates listed Table 4 below. While TxDOT districts developed their own Regional ITS architectures over time, many of the ITS architectures were not updated as new ITS projects were developed at a district level.

Table 4: Listing of TxDOT Districts with ITS Architectures and ITS Deployment Plans

TxDOT District / Region	Year Developed	TxDOT District / Region	Year Developed
Amarillo	2003	Lubbock	2003
Atlanta	2003	Lufkin	2005
Austin*	2015	Paris	2005
Beaumont	2003	Permian Basin (Odessa)	2005
Brazos Valley (Bryan)	2004	San Angelo	2004
Childress	2003	San Antonio	2007
Corpus Christi	2003	Tyler	2003
Del Rio	2004	Waco	2004
Eagle Pass	2013	West Central Texas (Abilene, Brownwood)	2004
El Paso	2003	Wichita Falls	2005
Laredo	2003	Yoakum	2005
Lower Rio Grande Valley (Pharr)	2003		

- The Austin Regional ITS Architecture was updated during 2015. Please refer to http://www.austinitsarchitecture.com/turbo/index.htm for more details.

4.4 Future Texas Regional ITS Architecture Integration

Given the large number of district-level ITS architectures that have been created in the state of Texas, the process involved in updating each architecture can be complex. Some districts may have more ITS projects to include than others. In addition, that district-level TSMO program plan may interconnect with other district program plans as adjacent districts may have the same mobility needs, formal processes, or shared corridors. An integration of neighboring district-level ITS architectures has not been performed to understand the potential integration opportunities that could exist at a larger regional level within the state.

It is recommended that TxDOT perform a consolidation of district-level regional ITS architectures in future years to reduce the amount of longer-term maintenance that is required with ITS Architectures. This effort can include the following activities to be conducted with TxDOT that can lead to an informed decision on how best to consolidate regional ITS architectures within the state.

1.4.1 Regional ITS Architecture Overview

Develop a brief overview of regional ITS architectures to describe what a regional ITS architecture is, its purpose and benefits, how it is used, who is involved in the development, updates and maintenance, and how it relates to and differs from a TSMO Program Plan. The overview can also describe system and technology issues that can be addressed by developing, adhering to, and maintaining a regional ITS architecture.

1.4.2 State of the Practice Review

Conduct a review of current practices by other state DOT’s, MPOs and other relevant transportation agencies with developing, updating and maintaining ITS architectures. The review should include the following information:

- The process used to develop, update and maintain ITS architectures as well as technical resources available to assist these processes.
- Lead agencies and their roles and responsibilities in architecture development, updates and maintenance.
- Frequencies of ITS architecture maintenance and updates, including both minor and major updates.
- Motivations for ITS architecture updates.
- Definitions of ITS architecture geographic boundaries.
- Methods to differentiate or combine mixture of urban and rural settings and ITS applications in a region or a state.
- References and tools used.
- Policies, guidance and literature offered by the relevant national government agencies, associations and organization (e.g. FHWA, AASHTO).

1.4.3 Data Collection

Collect relevant available information from various sources to perform an investigation of options and strategies for updating regional ITS architectures. This includes collaboration with consultants that are currently providing services to the State that are complimentary to Regional ITS Architectures. The information to be collected should include:

- Population and boundaries of MPOs, current regional ITS architectures, Metropolitan and Micropolitan Statistical Areas (MMSA), Combined Statistical Areas (CASA) and Districts.
- Characteristics of districts (e.g. metro, urban, rural).
- Coverage areas of current regional ITS architectures.
- ITS services and functions in each MPO region and district as defined in current architectures.
- Major corridors and travel characteristics (Annual Average Daily Traffic, peak period volumes, travel patterns) using Transportation Planning & Programming maps or another TxDOT provided source.
- Conduct an online survey of all TxDOT Districts and MPO's to collect data on:
  - TMCs, coverage areas, and responsibilities.
  - Roadway maintenance areas and responsibilities.
  - Commercial vehicle inspection and enforcement.
  - International border crossings and inspection.
  - Social and economic ties between adjacent MMSAs.

In addition to collecting information from District Level TSMO Program Plan and ITS Implementation Plan, other sources for data collection can include the following:

- Special studies of state and regional significance (e.g., Cooperative Automated Transportation Plan, Freight Study, Corridor Studies).
- MPO transportation and ITS planning/study documents.
- Regional ITS architectures.
- Surveys regarding ITS systems, services and functions in each MPO region, districts and major corridors.
- Transportation Planning & Programming Maps for traffic data of major corridors.
- US Census data.

Additional data may be obtained through surveys of TxDOT Districts and MPO staff to gather their inputs on how to provide and improve the usefulness and relevance of the ITS architecture outputs for regional planning and project development. Surveys can be conducted either through staff meetings or via web-based surveys distributed online.

1.4.4 Data Review and Analysis

Based on analysis of data collected, alternatives may be identified for defining ITS architecture regions. The objectives of this analysis are to identify feasible and logical models that will:

- Make individual regional ITS architectures more relevant to their corresponding regions and stakeholders.
- Make architectures more useful for planning and project development.
- Provide complete statewide coverage.
- Reduce the number of architectures.
- Comply with federal requirements and regulations.

The following factors can be considered in this analysis to define regions for ITS architectures:

- Geographic, demographic, social and economic characteristics.
- Transportation system and operational characteristics.
- Emphasis of ITS solutions.
- Types and concentration of ITS deployments.
- Responsibilities for planning, construction and maintenance.
- Roles, locations and coverage of regional TMC.
- Travel corridors and proximity.
- Travel patterns between a MMSA and adjacent MMSA or counties.
- Social and economic ties between adjacent MMSA or counties.

Data may be summarized in documents, spreadsheets, and maps. A series of maps may also be produced to aid in visualizing the information and analysis results.

1.4.5 ITS Architecture Update Alternatives and Strategies

Based on the results of information analysis, alternatives for defining regions for ITS architectures may be developed. The grouping of areas (e.g. MMSA, counties, districts) can be based on similarities. Each alternative may present a different grouping of area, and all alternatives can provide complete statewide coverage.

For each identified alternative, methods, and strategies to update, maintain, and use the regional ITS architectures should be investigated. This should include identification and analysis of pros and cons of each alternative and its underlying methods/strategies for implementation. These alternatives should then be ranked by preference by TxDOT staff.

4.5 Recommendations

Based on the preference ranking, a model for defining regions for ITS architectures should then be recommended along with methods and strategies to implement this model. An ITS Architecture Program Plan should also be developed to include the following information:

- Overview of regional ITS architectures.
- State of the practice review.
- A listing of the existing regional ITS architectures in Texas, including brief descriptions of the architectures and their coverage boundaries, and links or directions on how to obtain the architecture documents and databases, and their relationships to the definition of the recommended regional ITS architecture model.
- Definition of regions for ITS architectures in Texas, including the boundaries of each region; region's general characteristics; groupings of regions (if applicable), methods and rationale of grouping cities and/or counties into a region; and relationship to the existing regional ITS architectures and their geographic boundaries.
- Key stakeholders for each region, and their roles and responsibilities in ITS planning, design, construction, operations and maintenance.
- Recommended stakeholder(s) for leading the ITS architecture development for each region.
- Stakeholders who should be involved in ITS architecture development for each region.
- Methods and strategies for TxDOT to communicate and educate regional stakeholders on how to obtain their support for the region definition and ITS architecture strategies recommended in the program plan.
- Recommendations on the ITS architecture website, including whether the current website for regional ITS architectures should be kept, updated or revamped; how the website should be updated and maintained; and who will perform the update and ongoing maintenance.
- Strategies, steps, methods and schedule for implementing the program plan.
- Estimated resource requirements for implementing the program plan.
- Available resources and tool kits to assist with developing and maintaining a regional ITS architecture.

5.0 Concept of Operations

The Concept of Operations (ConOps) is a critical early step of the systems engineering process and provides a description of how one or more ITS technologies will operate in non-technical terms. It is presented from the viewpoints of the stakeholders that have roles and responsibilities in its operations. The ConOps provides a bridge between the original needs that motivated the project to begin with and the specific technical system requirements that will be developed in the subsequent stage of the Systems Engineering process. The ConOps defines the who, what, when, where, why, and how for the implementation of ITS technologies by:

- Establishing stakeholder agreement on how the ITS technologies are to be operated, who is responsible for what, and what the flows of communication are between technologies.
- Defining the preferred high-level system concept compared to other alternatives.
- Defining the operational and support environment in which the ITS technologies will operate.
- Developing high-level requirements, especially user requirements.
- Providing the criteria to be used for validation of the completed system.

The recommended sections to be included within a ConOps document are presented in Table 5 below.

Table 5: Concept of Operations Template Outline and Content

ConOps Section	Sub-sections and General Content
Overview	Provide high-level background description of the project. Address the following: ▪ Project identification. Include the formal project name and any associated project identification numbers. Purpose and intended audience. ▪ Purpose of ConOps is to communicate an understanding of the user needs and how the proposed project and system will meet those needs, as well as form the basis for more detailed system requirements development, verification, and system validation. Audience is generally non-technical program management and sponsors, but can also include technical management, system developers, and operations managers and operators. Overview of the document. ▪ Summarize main sections of the document. ▪ High-level overview of the proposed system. ▪ Briefly state the purpose of the proposed system or subsystem to which the ConOps applies. Stakeholders. ▪ Identify the project stakeholders and system users, which can include the project sponsor, system owner, user agencies, maintenance / support entities, law enforcement / first responders, and the centers or sites that will operate the system. Include general roles and responsibilities. Document references.
Current System or Situation	Describe the current system that is to be removed / replaced / upgraded. ▪ Background of current system. Describe the current system or situation, including the background, mission, and objectives of the current system. Operational Constraints. ▪ Describe the limitations of the current system. Description of the Current System or Situation. ▪ Provide thorough description on the current system. Support Environment. ▪ Describe how the system is supported and maintained.

ConOps Section	Sub-sections and General Content
Change Justification	Describe the current system that is to be removed / replaced / upgraded. ▪ Introduce the reasons for the proposed system. ▪ Identify user needs that the project aims to meet or accomplish. Essential first step is to determine what is to be accomplished with the system. The system validation step will review if the project has succeeded in meeting the needs.
Concepts for the Proposed System	Describe the Proposed System in the following sections: ▪ Background, Objectives, and Scope. Can refer to prior planning documents or other documents that identify the system. Distinguish differences from the existing system. Operational Policies and Constraints. ▪ Can include hours of operation, staffing, space, hardware, and software constraints. Description of the Proposed System. ▪ Important to keep description simple and clear so all intended readers can fully understand. Graphics and pictorial tools should be used wherever possible. Modes of Operation. ▪ Examples can include standard, after hours, maintenance, diagnostic, emergency, training, fail-safe, or backup modes. User Involvement and Interaction. ▪ Types of user interaction may include skill levels / roles / work activities, methods of interacting with the system, operator use of the system in different modes. Assumptions and Constraints that are applicable to the previously identified changes that may affect the system. Risks. ▪ List any risks identified with the proposed changes to the system or with the management of the schedule or budget. ▪ Support Environment. ▪ Document the agency support environment and maintenance concepts for the proposed system.

ConOps Section	Sub-sections and General Content
Operational Scenarios	Operational scenarios are developed to illustrate how the proposed system should operate under normal and other potential circumstances. ▪ Describe how system users – TMC operators, safety service patrollers, police, maintainers, etc. – interact with the system in normal conditions and other potential circumstances. ▪ Show how the system addresses any operational, maintenance, or failure situations that could reasonably arise. ▪ Scenarios can include, but not be limited to, normal conditions, lane closure incidents, truck rollover hazardous materials spills, special events, emergency events, maintenance scenarios, system failure scenarios, and inclement weather conditions.
Summary of Impacts	Describe and summarize the operational impacts of the proposed system from the users' perspectives.
Analysis of the Proposed System	Provide analysis of proposed system in the following sections: ▪ Summarize the major operational alternatives considered, the trade-offs among them, and the rationale for the decisions reached. ▪ Summarize cost, schedule, and procurement options. ▪ Describe how remaining steps of the Systems Engineering process will be applied. ▪ Identify performance measures that will be needed to validate the success of the project in meeting goals and user needs.

The amount of detail that TxDOT districts should include within ConOps documents will depend on the anticipated impact of the ITS project to operations. For example, the integration of multiple ITS technologies that will be operated by multiple independent stakeholder agencies will require the participation and input from those agencies to establish clear and detailed description of their new procedures and possibly examine alternative approaches. However, for a simpler system that requires little operator involvement and no coordination among multiple stakeholder agencies, the ConOps document may only be a couple of pages long. Regardless of project size and complexity, the ConOps should describe all possible operational modes, both normal and failure, as seen by each stakeholder through a series of operational scenarios. TxDOT Districts throughout the state have had experience with the development of ConOps documents for large scale and complex ITS projects. Below are examples from metro area districts of the state:

- **Austin I-35 Integrated Corridor Management (ICM)**: An I-35 Integrated Corridor Management (ICM) ConOps was completed in November 2016 to provide strategies for improving regional mobility-related objectives, but not to give specific system requirement details. It established the framework to create a cross-network travel management plan for the Austin area. Several operational scenarios were identified to be analyzed, modeled, and simulated to evaluate the benefits of recommended travel strategies. Following the ConOps document, stakeholders continued to coordinate and refine system requirements as the project evolved through the project development life cycle.

- El Paso IH-10 Integrated Corridor Management System: This ConOps was developed in February 2017 as part of the United States DOT ICM Initiative. The ICM concept involves the operational coordination of multiple transportation networks and cross-network connections comprising a corridor, and the coordination of the different agencies and stakeholders responsible for corridor mobility. The ICM System is referred to as a “system of systems” that connects the transportation management systems of the individual networks, provides decision support, and enables joint operations. The IH-10 corridor in El Paso consists of freeway, arterial, and bus transit networks and connects major employment centers and two major international ports of entry to Mexico.

To foster adoption of the development ConOps documents for all ITS projects, it is recommended that different types of ConOps templates are developed to accommodate varying sizes and complexities of ITS projects throughout the state. This can establish a consistent application of the early critical step of the systems engineering process by all TxDOT districts. Further definition would need to be provided for the categories of ITS projects and how TxDOT districts could determine which template would apply to their ITS projects. Once completed, TxDOT districts and their project teams could then download the most recent version of the ConOps template document for their ITS projects.

6.0 Recommendations

TSMO strategies include a broad range of solutions to address how integrated strategies may be implemented in a coordinated manner. Recommended strategies related to systems engineering include the following:

- Develop Systems Engineering Review Form to ensure that the systems engineering analysis meets the minimum requirements as defined in CRF 940.11.
- Establish statewide standards on use of systems engineering by districts.
- Develop statewide systems engineering management plan for districts.
- Develop statewide template for other systems engineering documentation.
- Review district ITS architectures and consolidate into regional ITS architectures for multiple districts.
- Develop statewide template for Concept of Operations documents.

Each of the above strategies are described in more detail on the following pages.

STRATEGY NO. 1

Develop Systems Engineering Review Form to ensure that the systems engineering analysis meets the minimum requirements as defined in CRF 940.11.

The systems engineering process should be applied for TxDOT funded ITS projects. A systems engineering Review Form should be developed to address the below requirements:

1. Concept of Operations – while integral throughout the entire systems engineering process, it helps generate System Requirements and System Validation processes once it has entered an O&M phase.
2. System Requirements – clearly defines what the system will do.
3. Architecture Requirements/High Level Design – organizes system functions into higher-level units.
4. Configuration Item Level Design – at this stage, the process moves from a functional perspective of what the system will do, to a definition of how it will accomplish the functions.
5. Component Level (Unit) Design/Detailed Design – detailed design of all elements of the system.
6. Software Coding/Hardware Fabrication – software code written, parts fabricated, system integrated.
7. Unit Testing – each subcomponent, or unit, which will exist within the greater system, is tested individually; they are verified by comparing them with the component level design.
8. Configuration Item Verification – takes the components past unit testing and begins to configure them for appropriate system operation.
9. Subsystem Verification – As subcomponents come together and are configured, they are tested to ensure proper operation
10. System Verification Acceptance Testing – This final testing step involves ensuring that all aspects perform as intended, and the system may be "accepted" for operation.
11. System Validation/Operations and Maintenance – system operates to fulfill its operational mission.

GOAL ALIGNMENT (Check appropriate areas)

Safety:	Yes	Mobility:	Yes
Reliability:	Yes	Asset Uptime:	Yes

COST (Low, Medium, High)

Initial:	Low	Recurring:	Low

TXDOT STAFF EFFORT (Low, Medium, High)

Low

STAKEHOLDERS (Yes or No)

Internal:	Yes	External:	No

TIMEFRAME (Near-term, Mid-term, Long-term

Near-Term

RETURN ON INVESTMENT (Low, Medium, High)

High

STRATEGY NO. 2
Establish Statewide Framework on Use of Systems Engineering by TxDOT Districts

Application of the systems engineering process to ITS projects reduces the risk of schedule and cost overruns and increases the likelihood that the implementation will meet the needs of all system users. Given that ITS projects will vary in size and complexity between metro, urban, and rural districts, the application of the systems engineering processes will also vary in terms of the amount of required documentation.

This TSMO strategy recommends having TxDOT's Central Office Traffic Division (TRF) establish a framework within which TxDOT districts can apply all types of systems engineering processes to ITS projects of varying scope throughout the state. This should include ITS projects and applications that integrate with the Lonestar™ central management software, as well as other ITS projects that address the various TSMO operations strategies previously identified. Further definition will need to be provided as to how much systems engineering documentation is required for various sizes of ITS projects. Small scale ITS projects that plans to integrate new ITS devices, such as CCTV cameras or DMS, with an existing software package, may require less documentation than larger scale ITS projects that integrate multiple planned systems to be operated by multiple different stakeholders.

GOAL ALIGNMENT (Check appropriate areas)

Safety:	Yes	Mobility:	Yes
Reliability:	Yes	Asset Uptime:	Yes

COST (Low, Medium, High)

Initial: Medium Recurring: Low

TXDOT STAFF EFFORT (Low, Medium, High)

Medium

STAKEHOLDERS (Yes or No)

Internal: Yes External: No

TIMEFRAME (Near-term, Mid-term, Long-term)

Near-Term

RETURN ON INVESTMENT (Low, Medium, High)

High

STRATEGY NO. 3
Develop Project Systems Engineering Management Plan Template for Districts

A Project Systems Engineering Management Plan (PSEMP) is a recommended document that will outline how the steps of the systems engineering process will be applied. A PSEMP details the systems engineering processes to be used throughout the ITS project and provides detailed information on the processes to be used. It is often drafted at two different stages, with agency project management staff creating a first draft with sufficient detail to identify the needed tasks and any important project constraints for review by a system designer. An updated draft is then completed by the project design team that will perform the subsequent tasks outlined in the PSEMP, including system requirements and details on how the requirements will be tested and verified.

This TSMO strategy recommends having TRF provide a PSEMP template document that can be used by TxDOT districts that plan to implement complex ITS projects that involve multiple planned systems to be operated by project stakeholders. A first draft of the a PSEMP template document can be filled out by TxDOT district project management staff with the applicable content for an ITS project, and then provided to project designers to be updated and reviewed by TxDOT project management staff prior to ITS project implementation.

GOAL ALIGNMENT (Check appropriate areas)

Safety:	Yes	Mobility:	Yes
Reliability:	Yes	Asset Uptime:	Yes

COST (Low, Medium, High)

Initial:	Medium	Recurring:	Low

TXDOT STAFF EFFORT (Low, Medium, High)

Medium

STAKEHOLDERS (Yes or No)

Internal:	Yes	External:	No

TIMEFRAME (Near-term, Mid-term, Long-term)

Near-term

RETURN ON INVESTMENT (Low, Medium, High)

High

STRATEGY NO. 4
Develop Statewide Template for All Types of Systems Engineering Documentation

In order to foster adoption of the steps of the systems engineering process, it is recommended that document templates become developed for use by TxDOT districts throughout the state. This can establish a consistent application of the systems engineering process by all TxDOT districts.

This TSMO strategy recommends having TRF develop document templates that can be designed in Microsoft Word with use of TxDOT's approved logo and document formatting practices. These documents can be structured by TxDOT so that all the appropriate sections and sub-sections are included within the template of each systems engineering document. TxDOT districts and their project teams can then download the most recent version of the template documents for use at various phases of the systems engineering process. Template documents can be developed for systems engineering processes including, but not limited to the following processes:

- Program Management Plan
- Concept of Operations
- System / Subsystem Requirements
- Requirements Verification Traceability Matrix
- System Verification
- System Acceptance Test Plan
- System Validation

GOAL ALIGNMENT (Check appropriate areas)

Safety:	Yes	Mobility:	Yes
Reliability:	Yes	Asset Uptime:	Yes

COST (Low, Medium, High)

Initial:	Medium	Recurring:	Low

TXDOT STAFF EFFORT (Low, Medium, High)
Medium

STAKEHOLDERS (Yes or No)
Internal: Yes External: No

TIMEFRAME (Near-term, Mid-term, Long-term)
Near-term

RETURN ON INVESTMENT (Low, Medium, High)
High

STRATEGY NO. 5
Review District ITS Architectures and Consolidate into Regional ITS Architectures for Multiple Districts

Given the large number of district-level ITS architectures that have been created in the state of Texas, the process involved in updating each architecture can be complex. Some districts may have more ITS projects to include than others. District-level TSMO program plans may interconnect with other district program plans as adjacent districts may have the same mobility needs, formal processes, or shared corridors. An integration of neighboring district-level ITS architectures has not been performed to understand the potential integration opportunities that could exist at a larger regional level within the state.

This TSMO strategy recommends that TRF perform a consolidation of district-level ITS architectures in future years to reduce the amount of longer-term maintenance that is required with ITS architectures. This effort should include a series of activities that can lead to an informed decision on how best to consolidate district ITS architectures within the state.

GOAL ALIGNMENT (Check appropriate areas)

Safety:	Yes	Mobility:	Yes
Reliability:	Yes	Asset Uptime:	Yes

COST (Low, Medium, High)

Initial: Medium   Recurring: Low

TXDOT STAFF EFFORT (Low, Medium, High)

High

STAKEHOLDERS (Yes or No)

Internal: Yes   External: Yes

TIMEFRAME (Near-term, Mid-term, Long-term)

Mid-term

RETURN ON INVESTMENT (Low, Medium, High)

Medium

STRATEGY NO. 6
Develop Statewide Template for Concept of Operations Documents

In order to foster adoption of the development ConOps documents for all ITS projects, it is recommended that different types of ConOps templates be developed to accommodate varying sizes and complexities of ITS projects throughout the state. This can establish a consistent application of the early critical step of the systems engineering process by all TxDOT districts.

This TSMO strategy recommends having TRF develop ConOps document templates that can be designed in Microsoft Word with use of TxDOT's approved logo and document formatting practices. These documents can be structured by TxDOT so that all the various sections and sub-sections are included within the templates of the ConOps documents. Further definition would need to be provided for the categories of ITS projects and how TxDOT districts could determine which template would apply to their ITS projects. Once completed, TxDOT districts and their project teams could then download the most recent version of the ConOps template document for their ITS projects.

GOAL ALIGNMENT (Check appropriate areas)

Safety:	Yes	Mobility:	Yes
Reliability:	Yes	Asset Uptime:	Yes

COST (Low, Medium, High)

Initial:	Low	Recurring:	Low

TXDOT STAFF EFFORT (Low, Medium, High)

Medium

STAKEHOLDERS (Yes or No)

Internal:	Yes	External:	No

TIMEFRAME (Near-term, Mid-term, Long-term)

Near-term

RETURN ON INVESTMENT (Low, Medium, High)

Medium

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