Texas Freight Network Technology and Operations Plan

Automated Vehicle Infrastructure, Connected Signing, and Data Concept of Operations

Texas Department of Transportation, Freight Planning Branch

Final: December 2020
## Contents

1.0 Introduction .................................................................................................................. 1

1.1 Project Overview ......................................................................................................... 1

1.2 Project Reports ........................................................................................................... 2

1.3 Stakeholder Engagement ............................................................................................ 3

1.4 Texas Multimodal Freight Network ............................................................................ 4

1.5 Summary of Existing Conditions and User Needs ..................................................... 8

1.6 Summary of Strategies and Conceptual Framework Report ....................................... 9

1.7 Purpose of the Concept of Operations Document ..................................................... 12

1.8 AV Infrastructure, Connected Signing, and Data Strategy Overview ......................... 14

1.9 Organization of the Document .................................................................................... 16

2.0 The Current Situation in Texas ..................................................................................... 17

2.1 Description of the Current Situation .......................................................................... 17

2.1.1 Mobility and Reliability ....................................................................................... 19

2.1.2 Safety .................................................................................................................. 24

2.1.3 Levels of Vehicle Automation ............................................................................. 25

2.2 Existing Systems ........................................................................................................ 27

2.2.1 Proprietary Digital Maps and Processing Components .......................................... 27

2.2.2 TxDOT LiDAR Surveys ....................................................................................... 28

2.2.3 TxDOT Roadway Inventory ............................................................................... 29

2.2.4 TxDOT Roadside Signing Programs .................................................................... 29

2.2.5 Dynamic Message Signs ...................................................................................... 29

2.2.6 Connected Vehicle Applications .......................................................................... 32

2.2.7 Traffic Management Centers ............................................................................... 32

2.2.8 TxDOT Real-Time Traffic Management ................................................................ 34

2.2.9 DriveTexas ........................................................................................................... 34

2.2.10 Highway Condition Reporting System .................................................................. 35

2.2.11 OS/OW Permitting System ................................................................................. 35

2.2.12 TxDOT Crash Reports and Records ..................................................................... 36

2.2.13 TxDOT Asset Management ............................................................................... 36

2.2.14 Smart Work Zones ............................................................................................ 37

2.3 Deficiencies in the Current Situation ......................................................................... 37

2.4 Profiles of User Classes ............................................................................................. 38

2.4.1 TxDOT Divisions .................................................................................................. 38

2.4.2 TxDOT Districts .................................................................................................... 39

2.4.3 Traffic Management Centers ............................................................................... 39

2.4.4 Texas Department of Public Safety ....................................................................... 39

2.4.5 Texas Department of Motor Vehicles .................................................................... 40

2.4.6 OEMs and Startups ............................................................................................... 40

2.4.7 Automated Trucks ............................................................................................... 40

2.4.8 Other Users .......................................................................................................... 40

2.5 User Needs .................................................................................................................. 41

2.6 Assumptions and Challenges ...................................................................................... 45

2.6.1 Assumptions ......................................................................................................... 45

2.6.2 Challenges ............................................................................................................ 46
Exhibits

Exhibit 1: Distribution of Stakeholder Types for Public/Private Sector Outreach ........................................... 4
Exhibit 2: Overview of Texas Multimodal Freight Network Assets ................................................................. 6
Exhibit 3: The Texas Multimodal Freight Network ............................................................................................. 7
Exhibit 4: 2018 TFMP Goals ............................................................................................................................ 8
Exhibit 5: Summary of Proposed FNTOP Strategies ....................................................................................... 10
Exhibit 6: Potential Integrated Services and Strategies ....................................................................................... 11
Exhibit 7: Formulation of Strategies from Proposal to Final Texas Freight Network Technology and Operations Plan ........................................................................................................... 12
Exhibit 8: Systems Engineering V-Model ........................................................................................................... 13
Exhibit 9: Illustrative Example of AV Infrastructure, Connected Signing, and Data System ........................................... 15
Exhibit 10: Texas’ Freight Mobility Plan Goals and Objectives Related to the AV Infrastructure, Connected Signing, and Data System ........................................................................................................... 17
Exhibit 11: Forecasted Total Freight Tons by Mode, 2016 and 2045 .................................................................. 20
Exhibit 12: Level-of-Service Descriptions ........................................................................................................ 20
Exhibit 13: Daily Level-of-Service on the Texas Highway Freight Network, 2016 ............................................. 22
Exhibit 14: Truck Buffer Time Index on the Texas Highway Freight Network, 2016 ......................................... 23
Exhibit 15: Commercial Motor Vehicle-Related Crashes on Texas Roads (2013 to 2017) ........................................... 25
Exhibit 16: Society of Automotive Engineers J3016 Levels of Driving Automation ............................................ 26
Exhibit 17: Digital Map Developed by Ford Motor Company of University of Michigan Test Site ......................... 28
Exhibit 18: TxDOT ITS Inventory - Dynamic Message Signs ............................................................................. 31
Exhibit 19: TxDOT Traffic Management Centers .............................................................................................. 33
Exhibit 20: DriveTexas Website (Statewide) ...................................................................................................... 35
Exhibit 21: Affiliated User Needs for the Automated Vehicle Infrastructure, Connected Signing, and Data System ................................................................................................................................. 42
Exhibit 22: Illustrative Example of AV Infrastructure, Connected Signing, and Data Strategy .................................................. 51
Exhibit 23: Automated Vehicle Infrastructure, Connected Signing, and Data Features and Functions .......................................................... 51
Exhibit 24: Advanced Data Processing System High-Level Architecture .......................................................... 59
Exhibit 25: Systems Diagram for the AV Infrastructure, Connected Signing, and Data Strategy .................................................. 61
Exhibit 26: Data Flow Diagram for the AV Infrastructure, Connected Signing, and Data Strategy .................................................. 61
Exhibit 27: Relevant Stakeholders for the Automated Vehicle Infrastructure, Connected Signing, and Data Strategy ................................................................................................................................. 71
Exhibit 28: Summary of Operational Scenarios ................................................................................................ 77
<table>
<thead>
<tr>
<th>Acronyms</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>Annual Average Daily Traffic</td>
</tr>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interfaces</td>
</tr>
<tr>
<td>ATA</td>
<td>American Trucking Associations</td>
</tr>
<tr>
<td>ATIS</td>
<td>Advanced Traveler Information System</td>
</tr>
<tr>
<td>ATMS</td>
<td>Advanced Traffic Management System</td>
</tr>
<tr>
<td>AV</td>
<td>Automated Vehicle</td>
</tr>
<tr>
<td>BTI</td>
<td>Buffer Time Index</td>
</tr>
<tr>
<td>C-V2X</td>
<td>Cellular Vehicle-to-Everything</td>
</tr>
<tr>
<td>Cap Metro</td>
<td>Capital Metropolitan Transit Authority</td>
</tr>
<tr>
<td>CAT</td>
<td>Cooperative Automated Transportation</td>
</tr>
<tr>
<td>CAV</td>
<td>Connected and Automated Vehicle</td>
</tr>
<tr>
<td>CCTV</td>
<td>Closed-Circuit Television</td>
</tr>
<tr>
<td>CMV</td>
<td>Commercial Motor Vehicle</td>
</tr>
<tr>
<td>ConOps</td>
<td>Concept of Operations</td>
</tr>
<tr>
<td>CRASH</td>
<td>Crash Reporting and Analysis for Safer Highways</td>
</tr>
<tr>
<td>CRFC</td>
<td>Critical Rural Freight Corridor</td>
</tr>
<tr>
<td>CRIS</td>
<td>Crash Records Information System</td>
</tr>
<tr>
<td>CTECC</td>
<td>Combined Transportation, Emergency &amp; Communications Center</td>
</tr>
<tr>
<td>CTR</td>
<td>University of Texas at Austin Center for Transportation Research</td>
</tr>
<tr>
<td>CTRMA</td>
<td>Central Texas Regional Mobility Authority</td>
</tr>
<tr>
<td>CUFC</td>
<td>Critical Urban Freight Corridor</td>
</tr>
<tr>
<td>CV</td>
<td>Connected Vehicle</td>
</tr>
<tr>
<td>DART</td>
<td>Dallas Area Rapid Transit</td>
</tr>
<tr>
<td>DMS</td>
<td>Dynamic Message Sign</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communications</td>
</tr>
<tr>
<td>DTM</td>
<td>Digital Terrain Model</td>
</tr>
<tr>
<td>ESAL</td>
<td>Equivalent Single Axle Loads</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicles</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>FNTOP</td>
<td>Freight Network Technology and Operations Plan</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GIWW</td>
<td>Gulf Intracoastal Waterway</td>
</tr>
<tr>
<td>HB</td>
<td>House Bill</td>
</tr>
<tr>
<td>HCRS</td>
<td>Highway Condition Reporting System</td>
</tr>
<tr>
<td>HOS</td>
<td>Hours-of-Service</td>
</tr>
<tr>
<td>HPMS</td>
<td>Highway Performance Monitoring System</td>
</tr>
<tr>
<td>I-10</td>
<td>Interstate 10</td>
</tr>
<tr>
<td>I-35</td>
<td>Interstate 35</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>I-45</td>
<td>Interstate 45</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>ITD</td>
<td>Information Technology Division</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation Systems</td>
</tr>
<tr>
<td>LiDAR</td>
<td>Light Detection and Ranging</td>
</tr>
<tr>
<td>LOS</td>
<td>Level of Service</td>
</tr>
<tr>
<td>M-69</td>
<td>Marine Highway 69</td>
</tr>
<tr>
<td>METRO</td>
<td>Metropolitan Transit Authority of Harris County</td>
</tr>
<tr>
<td>MMS</td>
<td>Maintenance Management System</td>
</tr>
<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
</tr>
<tr>
<td>MPO</td>
<td>Metropolitan Planning Organization</td>
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<tr>
<td>MUTCD</td>
<td>Manual on Uniform Traffic Control Devices</td>
</tr>
<tr>
<td>NHTSA</td>
<td>National Highway Traffic Safety Administration</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operations and Maintenance</td>
</tr>
<tr>
<td>OBU</td>
<td>On-Board Unit</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturers</td>
</tr>
<tr>
<td>OS/OW</td>
<td>Oversize/Overweight</td>
</tr>
<tr>
<td>PAAC</td>
<td>Port Authority Advisory Committee</td>
</tr>
<tr>
<td>PII</td>
<td>Personally Identifiable Information</td>
</tr>
<tr>
<td>PMIS</td>
<td>Pavement Management Information System</td>
</tr>
<tr>
<td>QR</td>
<td>Quick Response</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio-Frequency Identification</td>
</tr>
<tr>
<td>RIMS</td>
<td>Regional Incident Management System</td>
</tr>
<tr>
<td>RSU</td>
<td>Roadside Unit</td>
</tr>
<tr>
<td>RTI</td>
<td>Research and Technology Implementation</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SB</td>
<td>Senate Bill</td>
</tr>
<tr>
<td>SOP</td>
<td>Standard Operating Procedure</td>
</tr>
<tr>
<td>SPaT</td>
<td>Signal Phase and Timing</td>
</tr>
<tr>
<td>STRATIS</td>
<td>South Texas Regional Advanced Transportation Information System</td>
</tr>
<tr>
<td>SWRI</td>
<td>Southwest Research Institute</td>
</tr>
<tr>
<td>SWZ</td>
<td>Smart Work Zones</td>
</tr>
<tr>
<td>TCFC</td>
<td>Texas Connected Freight Corridors</td>
</tr>
<tr>
<td>TFMP</td>
<td>Texas Freight Mobility Plan</td>
</tr>
<tr>
<td>THFN</td>
<td>Texas Highway Freight Network</td>
</tr>
<tr>
<td>TMC</td>
<td>Traffic Management Center</td>
</tr>
<tr>
<td>TMFN</td>
<td>Texas Multimodal Freight Network</td>
</tr>
<tr>
<td>TMUTCD</td>
<td>Texas Manual on Uniform Traffic Control Devices</td>
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</tbody>
</table>
1.0 Introduction
The Freight Network Technology and Operations Plan (FNTOP) is anticipated to be the most comprehensive freight technology planning effort among state Departments of Transportation (DOTs) in the U.S. The FNTOP intends to outline potential strategies to guide technology- and operations-related investments on the Texas Multimodal Freight Network (TMFN). The FNTOP includes a review of current and future transportation challenges, opportunities, and the development of user needs informed by focused public and private sector engagement. The FNTOP is anticipated to be an invaluable resource to help public agencies and the private sector effectively plan for future deployments of freight technologies, working in partnership across all modes of freight transportation.

This document—titled Concept of Operations—discusses key information for the Automated Vehicle Infrastructure, Connected Signing, and Data strategy, which was one of the strategies identified in the FNTOP and recommended by stakeholders for advancement to the ConOps phase. The objective of a ConOps is to describe the operation of the proposed system in a non-technical and easy-to-understand manner. How the system is to be used and its anticipated benefits is described from multiple stakeholder viewpoints as a way to provide a bridge between the needs that motivated the project and the specific technical requirements.

1.1 Project Overview
The primary goal of the FNTOP is to develop a comprehensive plan advising TxDOT on deploying technology based operational strategies to improve freight transportation safety and mobility in Texas. The main objectives of this project include:

- Identify and assess technological and operational strategies being used on the TMFN or could be used in the future to improve safety, mobility, and facilitate economic competitiveness;
- Identify and assess the Texas Department of Transportation’s (TxDOT) needs, challenges, and opportunities in terms of physical Intelligent Transportation Systems (ITS) and related infrastructure, digital framework and related infrastructure, operations, staffing and expertise, and state-wide, corridor, urban, and rural needs and partnerships;
- Assess the TMFN’s current and future technological and operational needs, as well as its readiness and adaptability potential associated with the impacts of existing and emerging technologies;
- Develop strategies, policies, programs, and projects to address technological and operational needs; and
• Develop an Implementation Plan and a set of Concept of Operations documents, with each focused on a near-term freight network technology “early win” deployment concept.

The FNTOP and Concepts of Operations will guide Texas’s strategic development and deployment of innovative multimodal freight transportation technologies, techniques, research, and methods.

1.2 Project Reports
The FNTOP is based on a detailed assessment of current and future needs, challenges, gaps, and opportunities that inform strategies and a stand-alone Implementation Plan. These assessments are compiled in the following technical reports:

• **Goals and Objectives Report.** Developed goals and objectives for the FNTOP in alignment with existing and ongoing planning efforts and stakeholder input.

• **State of the Practice Assessment Report.** Assessed the state of the practice regarding freight-related groups, policies, and initiatives in Texas, in addition to existing and emerging domestic and international freight technological and operational developments.

• **Inventory of Existing Conditions Report.** Identified ITS assets, applications, and programs that exist on the TMFN, as well as summarized operational and management processes related to TxDOT and partner use of technology infrastructure.

• **Stakeholder Outreach Summary Report.** Summarized discussions and feedback collected at Texas public agency meetings, deeper-dive discussions with various TxDOT Divisions, Cooperative Automated Transportation (CAT) meeting, Port Authority Advisory Committee (PAAC) meeting, FNTOP regional stakeholder meetings, TxDOT stakeholder webinar workshop, FNTOP briefing with private and public sector stakeholders, as well as the set of one-on-one stakeholder interviews conducted.

• **User Needs Assessment Report.** Identified and assessed the technological and operational needs of the TMFN based on public and private sector stakeholder feedback, which were combined with initial research efforts to establish a set of FNTOP User Needs.

• **Strategies and Conceptual Framework Report.** Documented FNTOP identified strategies that are relevant to the goals and objectives of the FNTOP and based on documented FNTOP User Needs. Identified details of the FNTOP identified strategies, including how they are prioritized and how they could fit together as part of a larger conceptual framework that builds upon the existing Texas ITS program.
• **Concepts of Operations.** Developed in-depth concepts of desired operations and maintenance requirements for the six FNTOP recommended strategies selected for Concept of Operations (ConOps) development.

• **Implementation Plan.** Identified near-term, medium-term, and long-term actions, in addition to considerations necessary for the rollout of each of the 10 FNTOP recommended strategies as they are transitioned from planning to design.

• **Freight Network Technology and Operations Plan.** Summarizes the entire plan development tasks, as well as incorporates the technical and stakeholder engagement tasks completed throughout this project in a final plan.

In an effort to keep up with technology trends, TxDOT is separately developing its CAT Strategic Plan. This statewide plan looks at strategies and opportunities for advancing emerging technologies, such as Connected Vehicles (CVs), Automated Vehicles (AVs), and electric vehicles (EVs). With a number of goals that relate to the TxDOT multimodal transportation network, the plan aims to put Texas at the forefront of innovation. Although the CAT Strategic Plan is separate from the FNTOP, it has overlapping goals and objectives that have been used to help inform the FNTOP’s efforts and identified strategies.

1.3 **Stakeholder Engagement**

The FNTOP began with research on existing freight initiatives at TxDOT to gain a better understanding of the current challenges faced by the Texas freight community. A diverse group of stakeholders were also engaged to solicit feedback and opinions on the current state of freight operations in Texas and the possible application of technology to improve future freight operations. The stakeholder interviews verified and supported many of the issues identified by the FNTOP, while also helping identify and prioritize potential strategies to address system deficiencies.

This outreach included public sector stakeholders (internal and external to TxDOT; federal, state, and local) and private sector stakeholders. A brief overview of the FNTOP outreach effort is provided below:

- **TxDOT Stakeholder Groups (Division Offices) –** This effort included key personnel from many TxDOT Divisions, including the Transportation Planning and Programming Division, Information Technology Division, Traffic Safety Division, Travel Information Division, Right of Way Division, Rail Division, Maintenance Division, Maritime Division, and Strategic Planning Division.

- **Freight Network Technology Regional Outreach** – This effort included discussing the FNTOP at the TxDOT CAT Meeting, PAAC Meeting, Houston (TranStar) Stakeholder Meeting, Dallas/Fort Worth Stakeholder Meeting, a dedicated breakout session at the 2019 Texas Mobility Summit in San Antonio, a stakeholder webinar workshop, and a FNTOP briefing with private and public sector stakeholders. At each meeting or session,
moderators collected feedback regarding challenges and opportunities associated with technology-based operational strategies to improve freight transportation safety and mobility in Texas.

- **Public/Private Sector Stakeholder Outreach** – This effort consisted of one-on-one phone and in-person interviews (total of 58) with stakeholder representatives in multiple freight modes, freight companies, railroads, original equipment manufacturers (OEMs), startups, industry groups, telecommunications companies, research institutes, MPOs, cities, federal government, and others. A breakdown by type of stakeholder, based on the 58 interviews, is shown in Exhibit 1.

** Exhibit 1: Distribution of Stakeholder Types for Public/Private Sector Outreach**

1.4  **Texas Multimodal Freight Network**

The TMFN consists of the state’s freight assets that are most important for moving the largest volumes of freight and that serve the state’s key freight intensive industries. Per the 2018 TFMP\(^1\), these assets cover:

- **Highways:** Highways are the predominant mode for freight movement within the state, providing first and last mile connections to rail facilities, maritime ports, airports, and pipelines, as well as serving long haul trips destined throughout the state and beyond. Texas has over 313,000 miles of public roadways – making it the state with the most

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\(^1\) Texas Department of Transportation, *Texas Freight Mobility Plan 2018*, March 7, 2018.
extensive highway network. 21,861 miles are on the THFN, with 745 miles designated as Critical Rural Freight Corridors and another 372 miles designated as Critical Urban Freight Corridors. In 2016, trucks accounted for 54 percent of total tonnage moved in Texas. Intrastate trucking tonnage is anticipated to grow significantly as more residents, businesses, and freight locate within the state.

- **Railroads:** With 10,539 track miles (all on the TMFN), Texas has more miles of rail and more railroad employees than any other state. Texas contains five of the seven rail crossings between the U.S. and Mexico, providing critical connections for trade between the two countries. Texas’ 49 shortline railroads serve as first or last mile railroads for Texas’ three Class I railroads (BNSF Railway, Kansas City Southern Railway Company, and Union Pacific Railroad), Texas’ maritime ports, and many of the state’s rail-served industries.

- **Ports and Waterways:** Texas handles the second highest volume of total maritime tonnage of any state in the nation with 21 maritime ports and the Gulf Intracoastal Waterway (GIWW) system and is the leading state for international maritime tonnage. Maritime port and waterway access are necessary to attract and support many businesses, including the petrochemical sector, one of the state’s most important industries. Nine of Texas’ 12 deepwater ports, and one of its nine shallow-draft ports are included on the TMFN. Texas’ 379-mile portion of the GIWW, referred to as Marine Highway 69 (M-69), is also a part of the TMFN. M-69 handles two-thirds of the waterway's traffic, moving approximately 86 million short tons of cargo annually.

- **Airports:** In 2016, six of the top 50 cargo airports in the U.S. (in terms of landed weight) were located in Texas. Out of Texas’ 24 commercial airports, seven are included on the TMFN. Air cargo tonnage is expected to grow at a higher rate than any other mode due to market changes such as the increase in e-commerce and the associated expectations for one- or two-day shipping.

- **Pipelines:** Texas has the most extensive pipeline network in the nation, with 426,000 total miles (59 percent intrastate and 41 percent interstate), carrying 826.6 million tons of cargo in 2016.

- **International Border Crossings:** Texas’ 20 commercial international border crossings are also all on the TMFN. Of those, 15 are commercial vehicle crossings, and the other five are rail crossings.

Exhibit 2 provides an overview of the assets designated as a part of the TMFN – namely key roadways, railroads, ports and waterways, airports, and international border crossings. Exhibit 3 maps out where these assets are located in Texas. The TMFN is important because it outlines the key corridors that facilitate the efficient and safe movement of goods in Texas and are the most critical for focused investment.
### Exhibit 2: Overview of Texas Multimodal Freight Network Assets

<table>
<thead>
<tr>
<th>Asset Type</th>
<th>Key Figures</th>
<th>Transportation Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway Centerline Miles</td>
<td>313,000</td>
<td>1.2 billion tons</td>
</tr>
<tr>
<td>- 21,661 miles on the Texas Highway Freight Network</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 745 miles of Critical Rural Freight Corridor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 372 miles of Critical Urban Freight Corridor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Railroads on the TMFN</td>
<td>10,539</td>
<td>441 million tons</td>
</tr>
<tr>
<td>- 3 Class I railroads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 49 Class III or shortline railroads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ports and the Gulf Intracoastal Waterway System</td>
<td>21</td>
<td>598 million tons</td>
</tr>
<tr>
<td>- 12 deepwater ports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 9 included on TMFN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 9 shallow draft ports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 1 included on TMFN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 379 miles of GINW, all on TMFN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial Airports</td>
<td>24</td>
<td>1.8 million tons</td>
</tr>
<tr>
<td>- 7 air cargo airports on TMFN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miles of Pipeline</td>
<td>426,000</td>
<td>837 million tons</td>
</tr>
<tr>
<td>- 59% intrastate</td>
<td></td>
<td></td>
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<tr>
<td>- 41% interstate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial International Border Crossings, all on TMFN</td>
<td>20</td>
<td>73.5 million tons</td>
</tr>
<tr>
<td>- 15 commercial vehicle crossings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 5 rail crossings</td>
<td></td>
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</tr>
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</table>

Source: Texas Department of Transportation, Texas Freight Mobility Plan 2018 – Executive Summary, March 7, 2018.
The 2018 TFMP identified eight goals and associated objectives that help inform and articulate TxDOT’s freight investment priorities, help define freight system investment needs,
and identify the desired future performance of the TMFN. Exhibit 4 summarizes these goals, some of which will be utilized later in this document to identify deficiencies in the existing system and justify deployment of the identified strategy.

**Exhibit 4: 2018 TFMP Goals**

<table>
<thead>
<tr>
<th>2018 TFMP Goals</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>Improve multimodal transportation safety</td>
</tr>
<tr>
<td>Economic Competitiveness</td>
<td>Improve the contribution of the Texas freight transportation system to economic competitiveness, productivity and development</td>
</tr>
<tr>
<td>Asset Preservation and Utilization</td>
<td>Maintain and preserve infrastructure assets using cost-beneficial treatments</td>
</tr>
<tr>
<td>Mobility &amp; Reliability</td>
<td>Reduce congestion and improve system efficiency and performance</td>
</tr>
<tr>
<td>Multimodal Connectivity</td>
<td>Provide transportation choices and improve system connectivity for all freight modes</td>
</tr>
<tr>
<td>Stewardship</td>
<td>Manage environmental and TxDOT resources responsibly and be accountable in decision-making</td>
</tr>
<tr>
<td>Customer Service</td>
<td>Understand and incorporate citizen feedback in decision-making processes and be transparent in all TxDOT communications</td>
</tr>
<tr>
<td>Sustainable Funding</td>
<td>Identify sustainable funding sources for all freight transportation modes</td>
</tr>
</tbody>
</table>

Source: Texas Department of Transportation, Texas Freight Mobility Plan 2018

1.5 **Summary of Existing Conditions and User Needs**

The FNTOP reviewed the existing ITS program in Texas, which represents the vast majority of TxDOT’s real-time traffic management applications that serve roadway user needs, including freight. TxDOT utilizes Traffic Management Centers (TMC) as one of the key tools to operate and manage its road network. TxDOT is a participant in several advanced mobility initiatives, including an Integrated Corridor Management (ICM) program, a freight signal priority project, and several Connected Vehicle initiatives; that said, the vast majority of the ITS and traffic management program resides in major metropolitan areas, with limited coverage or response capabilities in rural areas. Relevant ITS programs in the context of this strategy are discussed later in Section 2.2. Further details on these programs and others can be found in the FNTOP State of the Practice Assessment Report and FNTOP Inventory of Existing Conditions Report.
User Needs for the FNTOP were informed by the FNTOP Goals and Objectives, the FNTOP State of the Practice Assessment Report, the FNTOP Inventory of Existing Conditions Report, and input from stakeholders. Relevant user needs that apply to this strategy are presented in Section 2.5 to aid with traceability of strategy features described later in the document. A full list of User Needs can be found as part of the FNTOP User Needs Assessment Report.

1.6 Summary of Strategies and Conceptual Framework Report
The FNTOP developed a series of technological strategies for improving freight operations in Texas. The strategies developed as part of the FNTOP consider the range of existing and emerging solutions available, based on traceability of the solutions to identified user needs prepared as part of the FNTOP User Needs Assessment. Exhibit 5 summarizes the potential strategies proposed to guide technology- and operations-related investments on the TMFN. Based on internal discussion and coordination with TxDOT, 10 of the 12 FNTOP strategies were advanced based on favorable feedback regarding direct relevance/importance to freight needs, uniqueness as a standalone strategy, and value as an application. The two strategies not advanced represented an infrastructure solution (Fiber Optic Expansion) and a strategy deemed to be too similar to another strategy (Freight Integrated Corridor Management) to be considered as a separate item to prioritize.

Key public and private stakeholders were engaged to obtain feedback on the 10 strategies, including suggested refinements, and priorities. Through outreach efforts, stakeholders were asked to rank the recommended strategies based on the following questions:

- Does the strategy add value to the Texas Multimodal Freight Network?
- Is the strategy likely to succeed in Texas?

A total of six strategies were recommended to advance to Concept of Operations development. There was consistent agreement among TxDOT and its stakeholders that these strategies had opportunity for adding value to the TMFN and were likely to succeed in Texas. The other strategies developed as part of this effort were either underway as part of a separate effort or deferred due to another TxDOT initiative. Exhibit 5 reflects the final recommendations for each strategy.
### Exhibit 5: Summary of FNTOP Identified Strategies

<table>
<thead>
<tr>
<th>Identified Strategy</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck Parking Availability System</td>
<td>Underway&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>High-Resolution Freight Traveler Information System</td>
<td>Advanced to Concept of Operations</td>
</tr>
<tr>
<td>Centralized Data Repository for Freight Applications</td>
<td>Deferred&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>AV Infrastructure, Connected Signing, and Data Safety Warning Detection System</td>
<td>Advanced to Concept of Operations</td>
</tr>
<tr>
<td>Smart Freight Connector</td>
<td>Advanced to Concept of Operations</td>
</tr>
<tr>
<td>Blocked Rail Crossing Traffic Management System</td>
<td>Advanced to Concept of Operations</td>
</tr>
<tr>
<td>Smart Work Zone Information System</td>
<td>Underway&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Statewide Traffic Operations Center</td>
<td>Advanced to Concept of Operations</td>
</tr>
<tr>
<td>Binational Traffic Operations Center</td>
<td>Deferred&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Freight Integrated Corridor Management</td>
<td>Not Advanced&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fiber Optic Cable Expansion</td>
<td>Not Advanced&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup>Included in other TxDOT ongoing initiatives  
<sup>2</sup>Better fulfills goals and objectives of other TxDOT initiatives  
<sup>3</sup>Not advanced due to similarities with Smart Freight Connector strategy  
<sup>4</sup>Not advanced due to being an infrastructure-focused commodity instead of a technological or operational application.

An overall technology framework was developed to demonstrate how the proposed FNTOP strategies could work together as an integrated statewide system. The framework helps illustrate the relationships between the FNTOP strategies and any overlapping opportunities that might allow for easier deployment. All strategies have the potential to be implemented together in functional groups or as stand-alone systems.

Exhibit 6 shows the relationship among integrated services and strategies.
Exhibit 6: Potential Integrated Services and Strategies
1.7 **Purpose of the Concept of Operations Document**

The development of a ConOps document for each of the six strategies selected for advancement is the next critical step necessary to create implementable solutions as part of the FNTOP. The objective of a ConOps is to describe the operation of the proposed system in a non-technical and easy-to-understand manner. How the system is to be used and its anticipated benefits is described from multiple stakeholder viewpoints as a way to provide a bridge between the needs that motivated the project and the specific technical requirements. Each required functionality must be traceable back to documented user needs prepared as part of the FNTOP User Needs Assessment to ensure that the ITS project addresses real-world issues. The ConOps document is used to collect feedback from the system users and other stakeholders and to validate key assumptions built into the system concept (e.g., who is responsible for what). By building support, gathering feedback, and refining the proposed concept, the ConOps document serves as a high-level guide for subsequent design efforts (e.g., System Requirements, High-Level Design, Detailed Design). It helps advance the strategy into these subsequent phases by reducing the risk of the strategy failing or being delayed due to a lack of agreement or understanding of the proposed concept.

The establishment of TxDOT and stakeholder priorities informed the selection of the six strategies that advanced to a ConOps. The development of FNTOP strategies, from proposal to ConOps, is outlined in Exhibit 7.

*Exhibit 7: Formulation of Strategies from Proposal to Final Texas Freight Network Technology and Operations Plan*

Projects that engineer systems—whether the project is a simple ITS deployment or a complex commercial airliner—follow what is called the Systems Engineering Process. This process identifies and outlines procedural steps of how the system is incrementally developed, how the system is incrementally validated by stakeholders, and how the system is to be
measured and accepted. The “V” Development Model, shown in Exhibit 8, is a visualization of one such process. This model was developed based on Systems Engineering industry standards and is part of U.S. Department of Transportation’s (USDOT) best practices for ITS projects. The development processes outlined in the model helps transportation agencies use common, consistent, and well-established systems engineering tools and processes to:

- Improve the quality of Intelligent Transportation Systems;
- Reduce the risk of cost and schedule overruns;
- Gain wide stakeholder participation;
- Maintain, operate, and evolve the Intelligent Transportation Systems;
- Maintain consistency with the regional and state ITS architectures;
- Provide flexibility in procurement options for the agencies; and
- Keep current with the rapid evolution of technology.

Exhibit 8: Systems Engineering V-Model


Development of the ConOps document is the first major step of the Decomposition and Definition phase of the V-Model, where ITS project concepts become more defined. It helps establish the simple expectations of the system so that stakeholders can understand what the project intends to do and understand how it will be later validated when complete.

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2 Federal Highway Administration California Division and Caltrans, Systems Engineering Guidebook for ITS Version 3.0 Website
1.8 AV Infrastructure, Connected Signing, and Data Strategy

Overview

This ConOps is focused on the AV Infrastructure, Connected Signing, and Data system, which was one of the priority strategies identified in the FNTOP and recommended by stakeholders for advancement to the ConOps phase. In the current AV state of the practice in Texas, AV truck systems experience issues when encountering complex roadway environments, such as road construction zones, areas where operational parameters are changing, and atypical geometric designs. This FNTOP strategy seeks to standardize and consolidate various sources of proprietary data into a digitized map that could be offered to all AV vendors as a service. Hosted on a centralized repository, the map would offer AV trucks information on the roadway environment; the data collected by the vehicle, in turn, would be uploaded to a database to ensure that the map is up-to-date and accurate. TxDOT and other public agencies would also contribute data from LiDAR surveys performed for construction projects.

The system also includes field elements to further clarify the roadway environment for AV trucks. Freight corridors and other facilities accessed by trucks would be instrumented with vehicle-to-infrastructure (V2I) technologies to communicate information wirelessly from roadside signs (static and dynamic) in a format that is understood by AV trucks. The solutions implemented as part of this system would allow AV trucks to navigate complex environments more easily by providing data on varying roadway geometries, real-time travel conditions, and operating restrictions such as weight and height limits. While some of the manual processes that are required today (i.e., AV trucks, as part of their safety protocols, generally require visual reading of the sign before taking actions), having an overlay of additional advanced information will help enhance an understanding of the environment in a manner that improves operational efficiency and allows the technology to more rapidly mature. In the long-term, as policies and protocols change, this system may eventually be adopted as a primary source of information by AVs to augment their onboard safety features.

Exhibit 9 provides an illustrative example of the AV Infrastructure, Connected Signing, and Data system that was previously discussed in the FNTOP Strategies and Conceptual Framework Report.
Exhibit 9: Illustrative Example of AV Infrastructure, Connected Signing, and Data System

Key objectives—collected through stakeholder outreach and other FNTOP efforts—that frame what this system is designed to do include:

- Improve AV freight mobility and safety in complex environments;
- Reduce AV disengagements caused by AV misinterpretation of roadway infrastructure, signage, lane markings, or temporary messaging;
- Collaborate to facilitate creation of a standardized, digital basemap of the Texas roadway environment that can be used by AVs;
- Collaborate to determine how the standardized digital basemap can be updated, such as through third-party or crowd-sourced data collection;
- Provide messages from static signs, dynamic signs, and traffic signals via wireless V2I broadcasts to provide supplemental information to AVs to improve situational awareness;

TxDOT Digital Map Database
- Houses LIDAR survey of many AV-approved roads
- Updated based on new geometries and work zones

Connected roadside signs broadcast relevant MUTCD and other message data

Connected ITS Assets broadcast relevant information

Automated truck compares TxDOT digital map against the real world to better navigate

Automated truck receives all broadcasts to supplement its on-board evaluation tools

Truck downloads digital map for use. Uploads updates to map as encountered
• Utilize map updates to disseminate current roadway information, such as infrastructure geometrics (e.g., work zones, low bridge heights, road widths, etc.) or offer information on crashes;³ and

• Continue coordination between TxDOT and OEMs/startups.

1.9 Organization of the Document
This document is one of the deliverables as defined under Task 2.6: Develop Concept of Operations from the scope of work for Cambridge Systematics, Inc.’s project number 160058.006 named Texas Freight Network Technology and Operations Plan. The scope of work document is TxDOT Work Authorization No. 6, Contract No. 50-6IDP5011. This ConOps covers the topic areas outlined in ANSI/AIAA-G-043 and IEEE Standard 1362, as recommended by the FHWA for ConOps development.

The remainder of this document is organized into the following sections:

• Section 2 – The Current Situation in Texas. This section describes current systems and technologies utilized by stakeholders and how each is being used, deficiencies of the existing systems, desired changes to the systems and priorities, and assumptions and challenges.

• Section 3 – Concept for the Proposed AV Infrastructure, Connected Signing, and Data System. This section contains a description of the desired system and high-level requirements, how it will address the concerns outlined in Section 2, how it will operate, and how users will interface with the system.

• Section 4 – Benefits, Impacts, and Alternatives of the AV Infrastructure, Connected Signing, and Data System. This section describes the expected operational and organizational benefits and impacts of the essential features of the new systems, the potential impacts during development, disadvantages and limitations of the proposed system, and alternatives and tradeoffs considered while developing the system concept.

• Section 5 – Operational Scenarios. This section identifies potential real-world situations for the system. Each scenario describes how stakeholders respond to and benefit from the implementation and operation of the new system.

• Section 6 – Next Steps. This section outlines the next steps of the Texas FNTOP following the development of the Concept of Operations documents, including the near-term development of the Implementation Plan.

• Section 7 – References. This section lists all references used in the creation of this document.

³ Once proper liability protections are in place for AV vendors and the public sector agency.
2.0 The Current Situation in Texas

The purpose of this section is to highlight the current situation in Texas, the existing systems currently in operation, and the deficiencies that are present. It later discusses the user classes that could apply to this ConOps document and the User Needs that support motivations to pursue a new AV Infrastructure, Connected Signing, and Data system.

2.1 Description of the Current Situation

The 2018 TFMP provides a comprehensive multimodal freight transportation plan for Texas, based on a decade of multimodal strategic planning initiatives and extensive stakeholder collaboration at the statewide, regional, and local levels to facilitate continued economic growth and efficient goods movement throughout the state. The TFMP and its related recommendations support the USDOT National Multimodal Freight Policy and national freight goals and include state-specific recommendations to explore technology options as part of policy and planning initiatives to enhance freight transportation system safety, management, operations, and asset preservation. Three of the goals and their associated objectives directly apply to the use of the AV Infrastructure, Connected Signing, and Data System, as outlined in Exhibit 10.

Exhibit 10: Texas’ Freight Mobility Plan Goals and Objectives Related to the AV Infrastructure, Connected Signing, and Data System

<table>
<thead>
<tr>
<th>2018 TFMP Goals</th>
<th>Description</th>
<th>Objectives Related to the AV Infrastructure, Connected Signing, and Data System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility and Reliability</td>
<td>Reduce congestion and improve system efficiency and performance</td>
<td>• Apply the most cost-effective methods to improve system capacity and reliability (including technology and operations).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Leverage technology to improve management and operations of the existing transportation system.</td>
</tr>
<tr>
<td>Economic Competitiveness</td>
<td>Improve the contribution of the Texas freight transportation system to economic competitiveness, productivity and development</td>
<td>• Strengthen Texas’ position as a global trade and logistics hub by improving and maintaining Texas’ multimodal freight network infrastructure and connectivity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Expand public-private and public-public partnerships to facilitate investments in freight improvements that enhance economic development and global competitiveness.</td>
</tr>
</tbody>
</table>
In the coming decades, AV trucks will transform how freight is moved on the nation’s highways. The benefits to the trucking industry are tremendous and wide-ranging with the potential to increase safety and mobility, reduce fuel consumption and emissions, and improve economic competitiveness. The 2018 TFMP recognized the potential of connected and automated vehicles (CAVs) for optimizing the multimodal transportation system to meet the increasing demand for freight by businesses, households, and industries. Benefits of CAV technologies include utilizing the capacity of the existing system more efficiently by enabling vehicles to maintain closer following distances (i.e., platooning). The technology also has the potential to spur the development of new applications and industries such as the use of automated shuttles for demand responsive transit and drones for package delivery and pipeline inspections.

To date, more than 28 states – including Texas – have passed legislation that allows AVs to operate on highways in some capacity. The legislation enacted by the Texas Legislature allows for the full commercial deployment of AVs, whereas some states only allow AV operations for testing purposes. The legislation includes provisions that support AV industry efforts to bring fully automated freight vehicles to market. In 2017, the Texas House passed House Bill (HB) 1791 that allows the use of connected braking systems. The same year, the Texas Senate passed Senate Bill (SB) 2205, which defined key aspects of AV operations, specifically what constitutes an automated driving vehicle and who is considered the owner and operator of the vehicle. The legislation allows for vehicles with automated driving systems to operate in the state without human drivers if the system meets federal motor

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4 National Conference of State Legislatures (NCSL). Autonomous Vehicles | Self-Driving Vehicles Enacted Legislation

5 Texas Legislature Online. H.B. No. 01791.
vehicle safety standards and conforms with the motor vehicle laws in the state. It essentially requires AVs operating in Texas to follow the same laws and regulations that apply to all vehicles in following traffic safety laws and meeting vehicle ownership registration and insurance requirements.⁶

In addition to the favorable regulatory environment for AVs, the freight infrastructure in Texas offers an ideal setting for AV trucks to operate, with its extensive network of highways that facilitate goods movement for U.S. industries and international trade. As noted in the 2018 TFMP, the state’s highways are the primary mode for freight transport, with over 313,000 miles of roads (most of any state) accounting for over half of the total tonnage moved in Texas.

### 2.1.1 Mobility and Reliability

Freight volume is expected to continue increasing in Texas, consistent with the upward trends in the state’s population and economy, in addition to the growth in cross-border trade with Mexico. According to the 2018 TFMP, highway tonnage is expected to double from 1.2 billion tons in 2016 to 2.5 billion tons in 2045. In the same time period, freight value is expected to increase from $1.7 trillion to $5.2 trillion. Exhibit 11 provides more detail on these forecasts. It also illustrates that trucks account for a large amount of total freight activity in the state. In 2016, trucks accounted for 54 percent of total tonnage movement in Texas. Freight tonnage moved by truck is expected to grow significantly by 2045, underscoring the importance of technological and operational advancements that can improve efficiency of the trucking industry.

A demographic challenge facing freight mobility in the future is the anticipated shortage of truck drivers needed to handle this expected growth in tonnage. According to the American Trucking Association (ATA), the trucking industry faced a shortage of over 60,000 drivers in 2018, which was an increase of nearly 20 percent over the previous year. ATA projects the shortage could increase to over 160,000 drivers by 2028 if current trends hold.⁷ The shortage is attributed to the inability to attract a younger and more diverse demographic to replace an aging work force where the average driver age is 46 years old.

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⁶ Texas Legislature Online. S.B. No. 02205.

⁷ American Trucking Associations, Truck Driver Shortage Analysis 2019.
Texas will need the capacity to handle the expected growth in tonnage. One of the goals of the 2018 TFMP was to measure the level-of-service (LOS) on the THFN and reduce the number of miles operating at LOS D or worse. Exhibit 12 defines the LOS ratings that were used in the 2018 TFMP, with supplemental descriptions provided by the Highway Capacity Manual and the American Association of State Highway and Transportation Officials (AASHTO) Geometric Design of Highways and Streets (“Green” Book). LOS is a qualitative measure for describing traffic operational conditions. LOS is a standard index of the service provided by a transportation facility and can range from LOS A (free-flow conditions) through LOS F (severely congested conditions). Approximately 72 percent of the state’s interstate system operated at LOS D or better, the lowest LOS considered acceptable for traffic operations. Exhibit 13 shows the 2016 daily LOS for the THFN.

**Exhibit 12: Level-of-Service Descriptions**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS A</td>
<td>Free flow. Traffic flows at or above the posted speed limit and motorists have complete mobility between lanes. Motorists have a high level of physical and psychological comfort. The effects of incidents or point breakdowns are easily absorbed.</td>
</tr>
<tr>
<td>LOS B</td>
<td>Reasonably free flow. LOS A speeds are maintained, maneuverability within the traffic stream is slightly restricted. Motorists still have a high level of physical and psychological comfort.</td>
</tr>
<tr>
<td>Rating</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>LOS C</td>
<td>Stable flow, at or near free flow. Ability to maneuver through lanes is noticeably restricted and lane changes require more driver awareness. Most experienced drivers are comfortable, roads remain safely below but effectively close to capacity, and posted speed is maintained. Minor incidents may still have no effect but localized service will have noticeable effects and traffic delays will form behind the incident.</td>
</tr>
<tr>
<td>LOS D</td>
<td>Approaching unstable flow. Speeds slightly decrease as traffic volumes slightly increase. Freedom to maneuver within the traffic stream is much more limited and driver comfort levels decrease. Minor incidents are expected to create delays.</td>
</tr>
<tr>
<td>LOS E</td>
<td>Unstable flow, operating at capacity. Flow becomes irregular and speed varies rapidly because there are virtually no usable gaps to maneuver in the traffic stream and speeds rarely reach the posted limit. Any disruption to traffic flow, such as merging ramp traffic or lane changes, will create a shock wave affecting traffic upstream. Any incident will create serious delays. Drivers' level of comfort become poor.</td>
</tr>
<tr>
<td>LOS F</td>
<td>Forced or breakdown flow. Every vehicle moves in lockstep with the vehicle in front of it, with frequent slowing required. Travel time cannot be predicted, with generally more demand than capacity. A road in a constant traffic jam is at this LOS, because LOS is an average or typical service rather than a constant state.</td>
</tr>
</tbody>
</table>

Source: 2018 Texas Freight Mobility Plan

Congestion on the THFN can contribute to additional delays and degradation to travel time reliability. As congestion increases, facilities become less capable of accommodating fluctuations to normal travel such as traffic incidents, work zones, and weather. The 2018 TFMP looked at the truck Buffer Time Index (BTI) on the THFN as a measure of travel time reliability. Buffer Time is the amount of extra time a traveler needs to account for above the average travel time to ensure being on time 95 percent of the time. The BTI normalizes that buffer time against the average travel time controlling for distance and typical daily congestion. For example, 15 minutes of buffer time relative to an average commute time of 30 minutes equates to a BTI of 0.50. Exhibit 14 shows the 2016 BTI on the THFN.

Source: 2018 Texas Freight Mobility Plan
Exhibit 14: Truck Buffer Time Index on the Texas Highway Freight Network, 2016

Source: 2018 Texas Freight Mobility Plan
2.1.2 Safety

Between 2013 and 2017, there were almost three million crashes on Texas roadways, with approximately 190,000 crashes involving commercial motor vehicles (CMVs), as reported in TxDOT’s Crash Records Information System (CRIS). The data revealed that CMV-related crashes have a greater impact on safety, resulting in a greater probability of serious injuries. During the reporting period, non-CMV-related crashes reported an average of 0.03 serious injuries per incident, while CMV-related crashes reported an average of 0.04 serious injuries.

Exhibit 15 shows the number of CMV-related crashes each year and the number of CMV-related crashes that reported serious injuries or fatalities. During the five-year period, the total number of CMV-related crashes grew at an average rate of five percent per year. CMV-related crashes involving serious injuries and fatalities combined represents five percent of the total CMV-related crashes. The number of serious injury and fatality-involved CMV-related crashes combined grew at an average rate of three percent per year, which is lower than the growth rate observed for non-serious CMV-related crashes.

Automated driving technologies have the potential to significantly reduce CMV-related crashes in Texas. According to the National Highway Transportation Safety Administration (NHTSA), human error is responsible for 94 percent of serious crashes. Automated driving would reduce the frequency and severity of crashes attributed to factors such as driver distraction, fatigue, and impairment. The CAT Strategic Plan estimates that automation could potentially reduce fatalities on Texas highways by 600 per year.  

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9 Texas Department of Transportation (TxDOT), Cooperative Automated Transportation Strategic Plan, February 2020.
2.1.3 Levels of Vehicle Automation

Recognizing the significance of the Texas market, OEMs and startups in the AV trucking industry are currently testing automated trucks on major interstate corridors, such as Interstate 10 (I-10) between California and Texas. As part of the stakeholder outreach conducted for the FNTOP, interviews were conducted with leading AV companies such as Embark Trucks, TuSimple, Kodiak Robotics, Peloton, and Ike Robotics that are currently operating in Texas or have concluded pilot programs. Discussions with these companies highlighted the industry’s focus on testing automated driving features on limited-access routes with the eventual goal of achieving full driving automation in the coming years. The progressive levels of driving automation according to the definitions set by the Society of Automotive Engineers (SAE) and adopted by USDOT are summarized in Exhibit 16.

Exhibit 15: Commercial Motor Vehicle-Related Crashes on Texas Roads (2013 to 2017)

Source: TxDOT Crash Records Information System
The AV trucking industry is interested in bringing Level 4 autonomy to commercial deployment in the next several years. The industry in Texas is currently road testing AV trucks with driver support features such as adaptive cruise control and lane centering. The AV trucks are operating with human safety drivers present to actively monitor traffic conditions and apply braking and steering if needed. Interviews with the AV industry performed during the FNTOP outreach process indicated that the companies are especially interested in applying self-driving technology to long-distance trucking, which is a sector that would benefit from automation given the limited driver hours-of-service (HOS) regulations and the worsening driver shortage. When asked how the public sector could benefit the industry as it advances towards Level 4 autonomy, representatives suggested anything TxDOT could do to help facilitate the electronic sharing of infrastructure conditions and parameters, specifically related to atypical or variable conditions, would help AV trucks safely navigate the roadway environment.

The desire by the industry for better information about the roadway environment presents an opportunity for the public sector to share data that could accelerate the development and proliferation of AV trucks. The AV Infrastructure, Connected Signing, and Data system could
provide data that adds to the coverage and depth of the proprietary maps developed by the industry so that AVs can better anticipate driving conditions in the course of testing self-driving technologies. TxDOT maintains roadway inventory datasets and generates real-time information on planned and unplanned road closures and work zones. This information could be digitized and disseminated to assist AV trucks with navigating complex areas with atypical geometrics and varying driving conditions. As the number of AV trucks in operation increases, more data on the roadway environment will be collected and mapped and more vehicle telemetry data will be available to validate and improve self-driving operations. This provides a pathway to facilitate private sector efforts to bring Level 4 autonomy to market in the next few years.

2.2 Existing Systems
This section discusses the existing traffic operations and management systems in Texas, highlighting systems on the highway network as well as systems utilized internally by the AV industry to conduct their operations. It is important to understand what systems and functionalities have already been deployed, so that the concept for the proposed system described in Section 3.0 can utilize relevant existing systems to support strategy implementation. Refer to the FNTOP Inventory of Existing Conditions Report for additional information on the majority of the existing systems included in this section.

2.2.1 Proprietary Digital Maps and Processing Components
Many AV companies currently operating in Texas utilize proprietary digital map databases to aid in vehicle navigation. These digital maps are built using environmental surveying data—primarily collected by LiDAR mapping, but may use other equipment as well—to represent the roadway environment to the AVs. AV vendors use this proprietary mapping software to aid their operational algorithms in navigating through the environment—while the AVs still require on-board equipment to assess the current state of their environment, the supporting digital maps help the vehicle better understand any geometric challenges and anticipate upcoming infrastructure conditions. Currently, each AV company that uses a digital map\(^\text{10}\) has their own proprietary standards and practices.

As an example, Exhibit 17 shows an image from a digital map for AVs, developed by Ford Motor Company at their University of Michigan AV test site.

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\(^{10}\) Some the AV truck operators that make up the FNTOP stakeholder group noted that their program intentionally does not utilize digital mapping, as their technology product aims to function potentially in unmapped environments.
These proprietary maps require an extensive mapping effort by each AV vendor, even though several vendors may be operating on the same road. If this effort could be consolidated, it would save these vendors from this mapping effort, allowing them to focus research and development more on the actual AV technology.

2.2.2 TxDOT LiDAR Surveys

During infrastructure projects that require design and engineering, TxDOT may conduct topographic LiDAR surveys. The three-dimensional maps produced by these surveys can be helpful for a number of applications, including highway, architectural, and site development. In many cases, these topographic surveys are used by the designer of record to develop the design, and are turned over to TxDOT as a survey file at the completion of the project. LiDAR surveys are currently conducted by the TxDOT Right of Way Division and Aviation Division.

Each LiDAR survey is a costly effort. While certain survey-related LiDAR efforts will continue to utilize specialized equipment due to a need to maintain good precision, having a broader LiDAR map with frequent updates would help in preliminary topographic efforts, such as master planning infrastructure studies.

2.2.3 TxDOT Roadway Inventory

TxDOT's TPP Division publishes its roadway inventory data annually. This data is submitted to the Federal Highway Administration (FHWA) as part of the Highway Performance Monitoring System (HPMS) program. It contains geographic information system (GIS) linework and roadway inventory attributes for the Texas network. Along with this data, TxDOT publishes annual roadway inventory reports that provide statistics on the use of public roadways in the state. These statistics include miles, lane miles, daily vehicle miles traveled, and daily truck vehicle miles traveled. The roadway inventory data can be found on TxDOT's Open Data Portal, which is managed by the TPP Division and houses all of TxDOT's GIS data.

The roadway inventory annual data can be helpful for analyzing conditions on TxDOT’s roadway network, such as for comprehensive planning efforts like the TFMP. It also provides the framework for more advanced roadway inventory mapping in the future.

2.2.4 TxDOT Roadside Signing Programs

TxDOT Traffic Safety Division (TRF) oversees signage programs in the State. They adhere to several standards for roadside signage, such as the Texas Manual on Uniform Traffic Control Devices (TMUTCD) and the Standard Highway Sign Designs for Texas. Traffic signals are considered traffic control devices and are installed, operated, and maintained by the State. However, for cities with populations that exceed 50,000, the local governments may share responsibilities with TxDOT for costs of constructing and operating a traffic signal on a state route. This transition of responsibility means the local cities have more direct involvement in setting the traffic signal timing plans in alignment with their needs and requirements, such as supplemental funding to support services like emergency vehicle preemption. To ensure that maintenance responsibilities are set forth, TxDOT enters into Municipal Maintenance agreements with each of the incorporated cities in the state. As mentioned in Section 2.2.13, roadside signing is maintained under the TxDOT Maintenance Management System (MMS).

While TxDOT’s signage program aims to keep signs current and presentable, the sheer volume of signing makes the effort of tracking down damaged or defaced signs more complicated. Sign replacement is not often in real-time, usually relying on citizen complaints, a sign inventory effort, or observation by passing TxDOT personnel to determine if something is missing. Simple sign damage can make it impossible for an AV to recognize the sign’s intent properly, which may cause it to miss or ignore an important message.

2.2.5 Dynamic Message Signs

TxDOT operates an extensive network of ITS field devices as part of its traffic management program, and Dynamic Message Signs (DMS) are one type of device that are commonly used by this program. DMS are electronic roadside signs that can broadcast changeable messages to road users, which may include public safety announcements, traveler information, incident information, or other key information. In comparison to static signs,
DMS can be changed in response to real-time events, which allows road users to make informed travel decisions to help improve their safety or mobility. Most DMS are located near major urban areas or along highly traveled routes where benefits to road users are often the greatest due to higher congestion rates and potential for incidents.

DMS currently broadcast their messages in alphanumeric text, based on guidance established in the TMUTCD. While most messages have standard formatting for incidents, some custom messages may use atypical formatting, such as “#EndTheStreak”, “Click It or Ticket”, or “Give ‘Em A Brake. Slow Down for Construction Workers” messages that are used in various states. Most human road users can intuitively infer what an atypical message is conveying, but deviation from a standard messaging format runs a risk of message confusion, primarily by machine algorithms that attempt to read these messages in a literal context. Currently, DMS in Texas do not have any additional mechanisms to clarify atypical messaging that are understood through human intuition.

Exhibit 18 shows the deployment of DMS at a statewide level. TxDOT operates over 980 DMS. Details on their locations can be found in the FNTOP Inventory of Existing Conditions Report.
Exhibit 18: TxDOT ITS Inventory - Dynamic Message Signs

Source: TxDOT Traffic Safety Division
2.2.6  Connected Vehicle Applications
CV applications have been implemented in isolated cases in Texas and nationally. Through the Texas Connected Freight Corridors (TCFC) Project, TxDOT is partnering with a number of public and private sector agencies to deploy CV infrastructure. The project focuses on the 865-mile Texas Triangle of Interstate 35 (I-35), I-45, and I-10. The TCFC Project, along with other efforts, is paving the way for more CV applications in the State.

The transportation industry views CV applications as being a solution for transportation problems in the future. It is anticipated to be a nationally-adopted communication standard for sending safety, infrastructure, and traffic-related messages to remote roadway users. In the context of this strategy, CV is likely a strong contender for moving data wirelessly and may support AV applications as it begins to rollout as a standard.

2.2.7  Traffic Management Centers
TxDOT utilizes TMCs as one of the key tools to operate and manage its road network. These TMCs utilize the ITS assets available in the District to improve traffic flow, respond to incidents, and provide public safety information at a widespread and coordinated level. Seven TxDOT TMCs currently operate in Texas; each is strategically located near urban areas where traffic volumes and road incidents are generally more frequent. Exhibit 19 shows the location of each TMC.

TMC operators publish messages to roadside DMS (discussed in Section 2.2.5) by entering the desired string of text into their Advanced Traffic Management System (ATMS) platform (discussed in Section 2.2.8). For newer DMS, TMC operators may enter a specific TMUTCD-compliant road sign to display on the DMS instead. In the current situation, TMC operators focus their message distributions with a human audience in mind; as a result, they strategize their message use to be intuitive to other people so as to minimize message confusion. While this is advantageous to human drivers, it may not be beneficial to machine algorithms that attempt to interpret roadside messaging, especially when the message uses an atypical or inferred format. As AVs become more common in the transportation system, TMC operators may need to rethink how messages are distributed.
Exhibit 19: TxDOT Traffic Management Centers
2.2.8 TxDOT Real-Time Traffic Management

All TxDOT TMCs operate their ITS programs using ATMS software. The ATMS software brings multiple ITS devices into one single platform for easy operator use and management within each TMC. Modern ATMS platforms allow for several systems to work collaboratively at the single press of a button or entry of a specific event type. TxDOT utilizes LoneStar for its TMCs, which is based on the ActiveITS system developed by the Southwest Research Institute (SWRI). ActiveITS is used in states other than Texas under different names. An exception to LoneStar’s use is in the Houston TranStar facility, which also utilizes the Regional Incident Management Platform (RIMS) Platform, developed by the Texas Transportation Institute (TTI), to assist with traffic data collection and other activities like law enforcement reporting.

These ATMS software packages send messages to the roadside DMS (either in text and/or graphic form, depending on the device) to inform motorists of traffic and safety information, but the design of the message set in this software package is currently based on human visual interpretation. The rollout of CVs may help expand the capabilities of the ATMS to send messages, such as limiting to a geofenced area or providing enhanced information, but it is unclear if these enhancements will sufficiently translate atypical messaging into a format that can be recognized by machine-based algorithms.

2.2.9 DriveTexas

DriveTexas serves as the online, public-facing database that provides real-time highway conditions throughout Texas. This data can include construction projects (ongoing and future), road closures, and other delays, as well as real-time traffic conditions. It is available as a web platform for browser users. DriveTexas receives and publishes data feeds from HCRS (Highway Condition Reporting System), as well as provides links to TxDOT’s ITS pages to show data from LoneStar. Exhibit 20 provides an illustration of the DriveTexas website.
As the traveler information platform for Texas, DriveTexas benefits from additional information on traffic conditions that can be made available. External third-party systems that can report real-time accurate and location-based traffic information would be a valuable contribution.

### 2.2.10 Highway Condition Reporting System

As part of construction projects to rebuild, rehab, or restore TxDOT’s existing highway infrastructure, road and lane closures are often requested. Road closure information is collected by local TxDOT Districts and entered into the HCRS as an active or planned construction project. This information is then reported as part of the DriveTexas platform, with color differentiation to signal when it is anticipated to occur. Districts may input all planned events, but DriveTexas only displays those planned events occurring in the next six weeks. DriveTexas reports the description, start/end location, the days and times of the closure, and what facilities are affected (e.g., lane 1, lane 2, etc.). This information is shown as an icon on the DriveTexas map for visual reference and contributes to the quality and accuracy of information disseminated to users of the TMFN.

### 2.2.11 OS/OW Permitting System

The Texas Department of Motor Vehicles (TxDMV) is responsible for licensing and registration for CMVs, as well as OS/OW CMV permit distribution. Their online permitting and GIS-based mapping system, the Texas Permitting & Routing Optimization System (TxPROS), allows customers to apply for and self-issue many of these permits.\(^{12}\) For many OS/OW

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\(^{12}\) Texas Department of Motor Vehicles. TxPROS Information & Tutorials.
routes, the route has to be driven in advance of permit issuance in order to verify that the route has the proper horizontal, vertical, curvature, and other geometric elements to accommodate the OS/OW load. While some of the commonly-used OS/OW routes have good information available on these geometric constraints, the large majority of potential route options in Texas would still need to be driven and manually verified in the current practice.

### 2.2.12 TxDOT Crash Reports and Records

TxDOT maintains crash records for the entire state. Texas law enforcement agencies are required to submit crash reports to TxDOT within 10 days of the crash occurrence. The Crash Reporting and Analysis for Safer Highways (CRASH) application allows for the electronic submission of the Texas Peace Officer’s Crash Report (form CR-3).

As part of the crash reporting and investigation process, law enforcement officers must determine the factors or conditions that contributed to the crash. Data collected by ITS devices, such as CCTVs, or private sector probe data can potentially be used to aid in crash reconstruction.

TxDOT’s CRIS is an online application that allows users to search for and purchase copies of the Texas Peace Officer’s Crash Reports. Law enforcement officers can use the CRIS mobile application to capture, submit, and supplement CR-3 Crash Reports.\(^{13}\)

### 2.2.13 TxDOT Asset Management

TxDOT maintenance personnel utilize management and assessment systems for roadway asset management. The Pavement Management Information System (PMIS) is an automated system for storing, retrieving, analyzing, and reporting pavement condition information. Information from the PMIS can be retrieved and analyzed by personnel to better understand pavement needs throughout the state.

The Texas Maintenance Assessment Program (TxMAP) collects maintenance performance data on approximately 4,000 one-mile roadway sections of the state highway system. Each year, the TxMAP report provides TxDOT with information on how effectively each District is performing maintenance. Data from TxMAP is uploaded onto TxDOT’s MMS, which contains detailed tools for analyzing and planning maintenance work.\(^ {14}\) The MMS contains specifications for maintaining level of service for various components, including traffic signals, signs, and pavement markings.\(^ {15}\)

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\(^{13}\) Texas Department of Transportation. Crash Reports.


2.2.14 Smart Work Zones

TxDOT is involved in many applications around the state that utilize ITS or some other form of technology. These applications are generally not part of LoneStar, as they are self-operating (i.e., Emergency Vehicle Pre-Emption), temporary (i.e., Smart Work Zones), or operated on TxDOT routes by some other agency.

TxDOT views ITS as a tool to be utilized in highway work zones to help improve public safety and mobility, as incidents within work zones often have significant impacts. The application of ITS for work zones is commonly referred to as “Smart Work Zones”, which is a term that can be used for a variety of strategies. TxDOT’s Traffic Safety Division provides “Smart Work Zone Guidelines”, which identify the eligible countermeasures considered as part of a Smart Work Zone, including:

- Temporary queue detection systems;
- Speed monitoring systems;
- Construction equipment alert systems (i.e., trucks entering highway alerts);
- Travel time systems;
- Incident detection and surveillance systems; and
- Overheight vehicle warning systems.

2.3 Deficiencies in the Current Situation

The FNTOP State of the Practice Assessment Report, interviews with the AV trucking industry, and input from other FNTOP stakeholders, identified several common deficiencies in the existing system, including:

- Many piloted Level 4 AVs have difficulties navigating through work zones, areas with atypical geometries, and roads with inconsistent signing – The FNTOP’s AV stakeholders noted that TxDOT could aid in their operations by providing statewide consistent work zone markings, pavement markings, and consistent signing, recognizing the significant cost associated with this type of infrastructure standardization. Additionally, it would require extensive effort from TxDOT to validate the consistency of each sign and pavement marking on an ongoing basis, given that signs can get knocked down and pavement markings can get obscured with little to no notice.

- Level 4 AVs that rely on digital maps have limited alternative route options – Most AV trucks utilize digital maps to support their operation. Due to the cost of mapping multiple roadway environments, these AV trucks are limited to the portion of the network that has been mapped. This generally correlates to roads where the operating environment is less complex and limited in variability (i.e., long stretches of open roadway). Some routes still require human safety drivers to assume vehicle control to complete the first and last miles of the trip.
- Public agencies lack access to private sector mapping data that could provide detailed information on infrastructure conditions and other observations – LiDAR sensors on AV trucks can capture 360-degree views of the environment surrounding the vehicle and offer data on the location of potholes, damaged signs, and other asset conditions. This information is highly valuable to TxDOT and the data could be leveraged to improve asset management and system preservation over time. Data on the roadway environment is currently maintained in proprietary maps held by the AV vendor. While many AV stakeholders acknowledged the value of this data, their ability to share it is limited by proprietary concerns.

- Lack of a centralized repository to share public and private sector mapping data – TxDOT compiles its own digital infrastructure maps for project-specific uses and general surveys. There is a lack of data exchange regarding these maps between the public and private sector. Each is collecting data and maintaining maps independent of the other; this limits data standardization and consistency. The ability to combine multiple maps using one unified standard would significantly expand the geographic coverage of the digitized routes, benefiting both the public and private sector.

- Level 4 AVs may use software that cannot interpret non-standard messaging used by TxDOT in certain cases – DMS messaging provides information to road users; a human driver is able to interpret custom messages that a machine may have trouble with (e.g., “#EndTheStreak”). Similarly, while TxDOT has adopted a state version of the MUTCD, not all road signs comply with the MUTCD; for example, custom signs are often permitted for use when applied consistently by a Department of Transportation (DOT). This can create the same issue of not being recognized by the AV’s software (e.g., “Drug Free School Zone”), especially when custom signs differ across state lines. This limits the ability of AVs to respond to certain messages.

2.4 Profiles of User Classes
The following contains a profile for users and stakeholders that would be involved with the AV Infrastructure, Connected Signing, and Data system.

2.4.1 TxDOT Divisions
The TxDOT Division offices handle a wide range of services for the agency. For various TxDOT initiatives, Divisions coordinate internally to serve as stakeholders and—depending on the topic—lead the initiative. Further details on the specific Divisions discussed as potentially being involved in this strategy can be found in the FNTOP State of the Practice Assessment Report and FNTOP Inventory ofExisting Conditions Report.

Several Divisions would be relevant to the AV Infrastructure, Connected Signing, and Data system. Given that significant data movement and storage may be required, the Information Technology Division (ITD) would likely have a role in developing standards and specifications to support TxDOT-owned communications network infrastructure that facilitates CAV
deployments. For edge devices, the Traffic Safety Division would likely be involved in the planning, implementation, and integration of any roadside communication devices, and would develop and maintain statewide specifications and standards for such devices. Other Divisions would include the Transportation Planning and Programming (TPP), given their interest in identifying and planning freight network improvements and their leadership of the FNTOP. Other Divisions would collaborate as well if the strategy overlaps with their efforts.

2.4.2 TxDOT Districts
TxDOT subdivides the State into 25 Districts that have local responsibility over building and maintaining state-owned roads and other applicable transportation infrastructure, including ITS devices and systems. TxDOT Districts would be key stakeholders that may be responsible for installing, operating, and maintaining any ITS field devices and components associated with this system, either as part of their ITS program or in collaboration with a Division-led initiative. Details on their exact roles and responsibilities for this unique initiative would need to be outlined prior to deployment. Additionally, TxDOT Districts may be an interested party to receive any available crowd-sourced reports from AVs of infrastructure issues, such as potholes.

2.4.3 Traffic Management Centers
The core business of the seven District TMCs is managing traffic and incidents using data collected from field devices such as traffic sensors, DMS, and CCTV cameras. TMC operators would be key stakeholders, identifying potential pilot corridors from a traffic operations perspective. They would also broadcast traffic information out to AV trucks through CV programs under this system. Through these CV programs, TMC operators would also have access to probe data collected by AV trucks.

2.4.4 Texas Department of Public Safety
The goals of the Texas Department of Public Safety (TxDPS) include enhancing highway and public safety, as well as statewide emergency management. The TxDPS Commercial Vehicle Enforcement Service checks the size, weight, and safety of trucks operating in Texas to ensure compliance with applicable state and federal laws. The Highway Patrol Division of TxDPS conducts law enforcement activities, primarily on rural highways where local police are not present. TxDPS also operates nearly 100 fixed commercial vehicle enforcement locations throughout the State to conduct these activities.

TdPS and its law enforcement counterparts are responsible for crash reconstruction, which utilizes a combination of witness accounts and scientific evidence to explain the sequence of a crash and the parties at fault. TxDPS would likely be an interested party in data that AVs can collect through their onboard equipment, as this onboard equipment may, at times, witness a crash between vehicles (either involving or not involving the AV itself). If the AV’s onboard equipment recorded such an event, that could be invaluable for reconstructing a crash that has occurred, similar to a credible video camera that records the event as it
occurs. AV vendors would need to be protected from liability if this crash information was provided, based on the use and accuracy of the data regarding how the crash occurred. This would need to be regulated through Texas laws, or through a policy that AV vendor data can be used to aid investigators in identifying other evidence to convey crash cause, but is not admissible in a court of law on its own.

2.4.5 Texas Department of Motor Vehicles
TxDMV handles licensing and registration for CMVs, as well as issues OS/OW CMV permits for which are applied by OS/OW carriers. TxDMV would be an end-user that could be interested in any available crowd-sourced digital map information, which (when vetted properly) could aid in their ability to select OS/OW routes that avoid low bridges and other troublesome infrastructure spots. Additionally, depending on the scope of how OS/OW routes are driven in the future for manual confirmation—such as if LiDAR mapping becomes a standard practice—TxDMV may become a contributor of data to a potential statewide digital map.

2.4.6 OEMs and Startups
A number of OEMs and startups are actively investing in and testing new technologies throughout the state of Texas. With an AV-friendly regulatory environment in the state, these companies are able to test Level 4 AVs with the presence of a safety driver. Companies also are testing AV operations with CV technologies, including truck platooning.

This group would be one of the main users of this system. As they operate on the Texas roadway network, their trucks would receive the data offered by this system, which would help improve the efficiency of their operations while operating at Level 4. They could also be users and contributors to any digital maps that are provided for the TxDOT road network, allowing them to have a greater understanding of the operating environment.

2.4.7 Automated Trucks
Highway trucking is the predominant mode for freight movement in Texas. Trucking is expected to continue growing significantly as more businesses and freight are located in Texas.

Truckers would be an end-user of this system, as some trucks may have partial or full AV features that can receive signals from connected infrastructure. Truckers with these features would experience improved operations, with the quicker proliferation of Level 4 SAE.

2.4.8 Other Users
Other users of the Texas roadway network would benefit from this system as end-users, specifically those users who own and operate vehicles with partial or full automation. Vehicles with partial or full automation would receive the same signals from connected
infrastructure as automated trucks. As their vehicles can better interpret the roadway environment around them, these users may notice improved operations in their travel.

2.5 User Needs
As part of the FNTOP, the User Needs Assessment developed a comprehensive list of User Needs identified through a gap assessment and ongoing stakeholder engagement. The specific needs and gaps from the User Needs addressed by the AV Infrastructure, Connected Signing, and Data system are summarized in Exhibit 21. The assessment prioritized these needs based on relevance, plausibility, and alignment with the 2018 TFMP goals and objectives. The User Needs were divided among seven high-level freight technology areas that were previously established in the FNTOP State of the Practice Assessment Report:

- Traffic Management;
- Advanced Traveler Information Systems;
- Dynamic Route Guidance;
- Data (I)ntegration and Analytics;
- Enforcement and Inspection;
- Connected and Automated Vehicles; and
- Intermodal Terminal Operations.

The naming convention for the user need ID includes the letter code listed above identifying the freight technology area to which it belongs to. For example, in Exhibit 21, UN-T4 represents the fourth User Need for the (T)raffic Management freight technology area. Each User Need is associated with one or more goals from the TFMP and is prioritized as follows:

- **High** – The need is a “must-have” and should be considered essential to the development of the FNTOP.
- **Medium** – The need is a “should-have” or desirable capability for which there is considerable interest, but is not necessarily critical to TxDOT.
- **Low** – The need is a “nice-to-have” or not viable in the near-term.

More information about the FNTOP User Needs and how this strategy can address them is available in the FNTOP User Needs Assessment Report, as well as FNTOP Strategies and Conceptual Framework Report.
### Exhibit 21: Affiliated User Needs for the Automated Vehicle Infrastructure, Connected Signing, and Data System

<table>
<thead>
<tr>
<th>ID</th>
<th>Preliminary User Needs</th>
<th>TFMP 2018 Goals</th>
<th>Priority</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Traffic Management Freight Technology Area</strong></td>
<td></td>
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</tr>
<tr>
<td>UN-T3</td>
<td>Need for more investment in congestion management strategies to address growing traffic.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>High</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-T4</td>
<td>Need to develop the Houston-Dallas-San Antonio triangle with new smart technologies to improve operations.</td>
<td>Safety, Economic Competitiveness, Asset Preservation and Utilization, Mobility and Reliability</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-T5</td>
<td>Need for more efficient and dynamic curbside management strategies to manage first and last mile issues.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-T7</td>
<td>Need for rural ITS in high-traffic freight areas to help support operations.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>Medium</td>
<td>Inventory of Existing Conditions, Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-T9</td>
<td>Need for advanced processing, such as machine learning or artificial intelligence, to help with traffic operations and incident detection.</td>
<td>Safety, Mobility and Reliability</td>
<td>Low</td>
<td>State of the Practice, Stakeholder Interviews</td>
</tr>
<tr>
<td></td>
<td><strong>Advanced Traveler Information Systems Freight Technology Area</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UN-A3</td>
<td>Need for more Dynamic Message Signs (DMS) on primary freight corridors to relay traffic information.</td>
<td>Safety, Asset Preservation and Utilization, Mobility and Reliability</td>
<td>High</td>
<td>Inventory of Existing Conditions, Stakeholder Interviews</td>
</tr>
<tr>
<td>ID</td>
<td>Preliminary User Needs</td>
<td>TFMP 2018 Goals</td>
<td>Priority</td>
<td>Source</td>
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<tr>
<td>UN-A10</td>
<td>Need for better advanced notice of height and weight restrictions on roads to improve safety.</td>
<td>Safety, Asset Preservation and Utilization, Mobility and Reliability</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-A11</td>
<td>Need for more advance notice of safety danger spots with high crashes, severe curves, or steep grades to warn drivers.</td>
<td>Safety, Asset Preservation and Utilization, Mobility and Reliability</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
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<tr>
<td></td>
<td><strong>Connected and Automated Freight Vehicles Freight Technology Area</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UN-C1</td>
<td>Need for more infrastructure improvements to support automated vehicles (roadway markings, signage).</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>High</td>
<td>State of the Practice, Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-C2</td>
<td>Need to provide a more collaborative environment to support the development/deployment of automated trucks in order to advance emerging transportation technologies.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>High</td>
<td>State of the Practice, Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-C3</td>
<td>Need for provide more collaborative environment to support more truck platooning deployments in order to improve efficiency.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-C4</td>
<td>Need for connected truck infrastructure in Texas to support connected trucks and improve safety.</td>
<td>Safety, Economic Competitiveness, Mobility and Reliability</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-C5</td>
<td>Need for more smart infrastructure to support automated vehicles on the TMFN.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>ID</td>
<td>Preliminary User Needs</td>
<td>TFMP 2018 Goals</td>
<td>Priority</td>
<td>Source</td>
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</tr>
<tr>
<td>UN-C6</td>
<td>Need to support AV only lanes to help advance automated freight technologies.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>Low</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-C7</td>
<td>Need to invest in automated aviation infrastructure to support Unmanned Aerial Devices for improved freight deliveries.</td>
<td>Economic Competitiveness, Mobility and Reliability, Multimodal Connectivity</td>
<td>Low</td>
<td>State of the Practice, Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-C9</td>
<td>Need for a non-proprietary digitized mapping standard for AV environments to support one common map for AV navigation.</td>
<td>Economic Competitiveness, Mobility and Reliability</td>
<td>Low</td>
<td>Stakeholder Interviews</td>
</tr>
</tbody>
</table>

**Intermodal Terminal Operations Freight Technology Area**

<table>
<thead>
<tr>
<th>ID</th>
<th>Preliminary User Needs</th>
<th>TFMP 2018 Goals</th>
<th>Priority</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN-I2</td>
<td>Need for more blocked rail crossing notification systems to improve safety and efficiency.</td>
<td>Safety, Mobility and Reliability, Multimodal Connectivity</td>
<td>High</td>
<td>State of the Practice, Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-I5</td>
<td>Need to support the use of more technology for automating intermodal terminal operations to increase efficiency at these terminals.</td>
<td>Economic Competitiveness, Mobility and Reliability, Multimodal Connectivity</td>
<td>Medium</td>
<td>State of the Practice, Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-I6</td>
<td>Need for more investment in technology and infrastructure to support ports in Texas and allow for growth in freight.</td>
<td>Economic Competitiveness, Asset Preservation and Utilization, Multimodal Connectivity</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>UN-I7</td>
<td>Need for more data collection around ports and other multimodal facilities to improve planning.</td>
<td>Economic Competitiveness, Multimodal Connectivity</td>
<td>Medium</td>
<td>Stakeholder Interviews</td>
</tr>
<tr>
<td>ID</td>
<td>Preliminary User Needs</td>
<td>TFMP 2018 Goals</td>
<td>Priority</td>
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<tr>
<td>UN-I11</td>
<td>Need for technology improvements at highway-rail grade crossings to improve safety.</td>
<td>Safety, Multimodal Connectivity</td>
<td>Low</td>
<td>State of the Practice, Stakeholder Interviews</td>
</tr>
</tbody>
</table>

2.6 Assumptions and Challenges

Several key assumptions and challenges would apply to a system that provides information on the roadway environment to AV trucks. These assumptions and challenges are identified in the following sections.

2.6.1 Assumptions

- **AV companies would adopt use of a non-proprietary digitized map to support their operations** – Current AV companies are focused on their own internal programs and operations, and have reiterated that their safety protocols require them to still monitor their operating environment. Those that use proprietary maps to help facilitate their understanding of the environment would need to align their data sources to receive external maps and pass the proper validation checks on this information to make sure it is useful. This may require some form of credentialing. The industry would be reluctant to share data from its proprietary maps if it erodes their competitive advantage, especially for industry leaders that have already invested significant resources in their mapping system. Over time, more of the industry could be receptive to data sharing since it is inefficient and cost prohibitive to map and continually update information on every roadway in the state.

- **Support for all Connected and Automated Vehicles** – The digital map and the V2I enabled road signs would support current and near-term AV truck pilot operations at Level 4 automation where the vehicle operates independently of the human safety driver under certain driving conditions. The strategy would also support Level 5 automation in the future when self-driving vehicles are expected to operate independently under all conditions without a human safety driver in the vehicle. V2I and vehicle-to-vehicle (V2V) communications under Level 4 and Level 5 automation would be supported as long as the AV trucks and roadside devices can communicate over a vehicle-to-everything (V2X) standard such as Dedicated Short Range Communications (DSRC) or cellular-based V2X (C-V2X). The solution would also work with AVs regardless of drivetrain (i.e., electric powered or not).

- **AVs are equipped with CV communications** – CV refers to any vehicle (automated or not) equipped for V2V and V2I wireless communications that can exchange information with CV-enabled roadside infrastructure such as traffic signals, DMS, and eventually road signs. The AVs operating in Texas are expected to be CV ready in the
next few years, given the projected rollout of CV. The V2I road signs deployed with the strategy would communicate wirelessly with AVs and non-AVs alike over a V2X communications standard to broadcast advisory, alert, and warning messages in a format that could be understood and processed by the CV on-board unit (OBU). USDOT is working with standards development organizations such as SAE and the IEEE to establish interoperable standards for V2I and V2V communications to transmit data between OBUs and with roadside units (RSUs) to support a range of CV safety and mobility applications.

- **Centralized hosting of the digital mapping repository and database** – TxDOT would be responsible for hosting the web application services and database system that maintains the digitized map of the roadway environment for the entire state. TPP would likely be responsible for hosting the centralized system since this digitized map would align with many of the roadway data sets that TPP currently collects and reports on.

- **Map update processes can be figured out** – Processes and procedures will need to be established to determine how a map update is made in the digital space, who is authorized to make an update, whether update confirmations are required, and how these updates are validated. Given the large amount of data collectors (e.g., TxDOT, AVs, etc.), it is likely that some crowd-sourcing will be pursued to conduct some of these steps. That said, the amount of data and the ability to accommodate regular updates will require an extensive amount of computational power, and proper validation will ensure that the map meets the defined accuracy requirements and maintains credibility with users.

- **Scope of AV truck communications** – The private sector would be responsible for providing reliable, high-speed wireless communications for the AV trucks to upload and download data from the digitized map. The private sector would also be responsible for equipping the AV trucks with CV-enabled devices to support V2V and V2I communications.

- **Scope of V2I communications** – MUTCD signs and DMS displaying information to human drivers would require transmitters that support V2I communications for broadcasting sign information and messages in a format understood by the AV truck. The information would also be broadcasted to all other vehicle types that are equipped for V2X communications. The V2I road signs deployed with the solution would communicate wirelessly with AVs and non-AVs alike over a V2X communications standard to broadcast advisory, alert and warning messages in a format that could be understood and processed by the CV OBU.

**2.6.2 Challenges**

- **AV Operators may be reluctant to adopt a new digital map standard** – AV operators may have concerns about the accuracy or reliability of this map information, and may
elect to continue their current practices. First movers and established companies in the industry may be reluctant to adopt a new standard if significant resources are already invested in the infrastructure to perform the initial mapping and data collection. They may also have concerns of migration costs to update the software to a new mapping standard, as well as adding features to recognize V2I broadcasts.

- **Signs are designed for human drivers** – Signs provide important information to drivers for navigating roads safely and efficiently. The signs use a variety of shapes, symbols, colors, and messages to convey information on traffic regulations, general warnings, permitted traffic movements, guidance to roadside services, guidance/advisories in work zones, guidance to recreational and cultural points-of-interests, guidance/advisories in school zones, and guidance/advisories in incident management areas. For those that are custom messages (either static or dynamic), it may be extremely challenging to convert all possible messages into a language that a machine can understand and utilize.

- **Changes in roadway geometry require immediate and frequent updates to a digital map** – Each year, numerous corridor improvement projects of all shapes and sizes take place across the state that involve reconstructing roadway alignments or interchanges. Ramp reconstruction also includes converting two-way frontage roads to one-way. Since these can be major lane width and use deviations, this requires the digitized maps to be updated on a frequent basis to reflect any changes.

- **Standardizing proprietary mapping data** – Achieving a consolidated and consistent basemap of the roadway environment will require a strong public-private-partnership between TxDOT and its public sector partners, the AV industry, and the respective standards organization that might certify the mapping standard (e.g., ISO). Data schemas, data transfer protocols, information security, data retention, and quality assurance are among the technical issues that need to be resolved. Memoranda of Understanding (MOUs) would be needed to delineate roles and responsibilities between parties. To date, no such effort has been undertaken, nor is a good first step process publicly available.

- **Potential legal liabilities for public agencies** – For the past several years, the AV industry has been operating self-driving vehicles on public roads in a number of states. Crashes involving self-driving vehicles pose a challenge for the legal system in determining the parties that are at-fault. This situation will worsen as the number of self-driving AVs increases. Public agencies that provide mapping data used by AV trucks could potentially be exposed to liabilities if it is determined that the lack of data or the accuracy of the data contributed to the unsafe operation of an AV truck, resulting in a crash with another vehicle or bicycle/pedestrian. Similarly, AV operators

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who are mapping data in real-time could face the same liabilities if their data collection is incorrect and results in the same outcome.

- **Lifecycle costs of deploying roadside V2I infrastructure** – The capital cost to deploy V2I communications infrastructure could be substantial based on the vast number of MUTCD signs and DMS installations across the state. Field deployments to support AV truck operations under Level 4 automation in the coming years would be limited to certain freight corridors where truck platoons are operated by the AV industry. In the future, field deployments would expand across the state to support Level 5 automation, where AV trucks could operate in more areas of the highway network without restrictions. This would require a detailed statewide inventory of MUTCD signs. Additionally, there would be ongoing operations and maintenance (O&M) costs that scale to the number of CV enabled signs. The effectiveness of the V2I infrastructure that broadcasts information to AV trucks from roadside MUTCD signs and DMS is dependent on the wireless communication devices functioning properly. This requires preventative maintenance to be performed routinely and device failures to be detected and troubleshooted in a timely manner. CV equipment would also be new to maintenance staff and require training on preventative maintenance and troubleshooting procedures.

- **Need for greater coordination within TxDOT** – Responsibility and oversight for the various sources of agency data that would populate the digitized map with layers of information—whether TxDOT-hosted or hosted by a private for-profit service—would be spread across various TxDOT Divisions and Districts. Data on the roadway environment that is updated periodically, such as work zones and roadway geometry, are overseen by TxDOT Districts, which are responsible for construction and maintenance. HCRS, which would populate the map with information on planned and unplanned road closures, involves District TMCs supplying information on planned closures. Keeping the agency data updated and accurate on the digitized map will require greater coordination within the agency and across TxDOT Divisions and geographic regions.
3.0 Concept for the Proposed AV Infrastructure, Connected Signing, and Data System

This section describes the proposed system. It provides an overview of the objectives; discusses ConOps essential features, capabilities and functions; and outlines the system-level operational environment, processes, and necessary support. The level of detail presented is intended to explain how the proposed system is envisioned to fulfill the user needs and requirements.

3.1 Objectives

The AV Infrastructure, Connected Signing, and Data strategy is designed to offer information on the roadway environment to improve efficiency and safety of automated freight vehicles. It is supported by a goal to improve the current state of AV operations in Texas, which—as discussed in greater detail earlier in this document—is a permissive environment where AV trucks are free to operate so long as they remain compliant with certain regulations. In the current AV state of the practice in Texas, AV trucks are operating up to SAE Level 4 autonomy with a human driver and safety engineer on many Texas roads with great success, but these AV truck systems can experience issues when encountering complex roadway environments, such as construction zones, areas where operational parameters are changing, and atypical geometric designs.

The Texas AV industry served as key stakeholders for the FNTOP and, when asked what TxDOT could do to help facilitate their operations, representatives identified “standard road construction zones” and “consistent signing” as issues TxDOT should address. While these topics seem straightforward, real-world compliance is much more difficult. Road signs get damaged, destroyed, or knocked over. Construction zones—despite having Maintenance of Traffic zones that comply with TxDOT standards—are often not precisely measured in the field, resulting in uneven construction barrel spacings, lane shifts that may be unique to the specific construction zone, and operational parameters (i.e., reduced speed limits) that are custom signed for that project.

Recognizing that standard work zones and consistent signing may be difficult to achieve, this strategy focuses on technology solutions. Most challenges for AVs come from navigating complex environments—be it atypical geometry or a non-standard work zone. AV software is able to understand and navigate its surroundings when it is standard infrastructure with clearly defined parameters. Many of these AVs operate on Texas roadways with assistance from proprietary mapping data, collected by the AV vendor through various methods (LiDAR, radar, cameras, and other sensors) prior to real-time operation. Although AVs have onboard instrumentation for identifying and assessing the roadway and any associated threats, the proprietary map provides AVs with a better understanding of the environment, by providing advance information of roadway characteristics. If the complex environments that challenge the operation of AVs were mapped digitally and offered to the AV’s mapping software, those
AVs could more competently travel through these environments, which would reduce “disengagements” and improve efficiency.

Similarly, AVs that can adapt their operations in response to roadside signage would benefit from any form of advance communication of sign instructions. Current AVs “read” the roadside signs through visual devices, but—as with human eyes—the AV’s onboard equipment cannot read a sign that is defaced, damaged, or knocked over. To enhance this recognition, this strategy explores equipping roadside signs with forms of V2I communications hardware to provide secondary information matching the sign’s message. Should the sign be occluded or unreadable, the V2I communications would allow the AV to still be able to interpret the sign’s message, allowing it to consider corrective actions even if its software mandates that it “see” the sign. This could be advantageous in situations where the AV “hears” the sign significantly in advance due to the longer range of V2I, but does not “see” the sign until nearly upon it. This could allow the software to anticipate the roadside sign and queue corrective actions in advance.

Additionally, atypical messages—especially those on DMS (i.e., #EndTheStreak)—could be converted into a machine-recognizable format so the AV would recognize what corrective action may be necessary.

This strategy recognizes that AV vendors have an obligation to set up their systems in the interest of public safety, meaning that their software ultimately has to safely operate in the roadway environment using its onboard sensors without any outside assistance. This strategy does not aim to replace those safety features, but rather help improve mobility and efficiency by offering the AV a greater awareness of its operating environment through technological tools. Many AV vendors have noted through stakeholder engagement that their software currently does not accept outside information, but given the challenges of navigating complex environments in the current AV state of the practice, it is likely that an enhancement from the outside is a necessary step to help advance this technology. This strategy offers several ambitious goals and ideas with recognition that this is extremely forward-thinking, but proposes them with the knowledge that only through continued public/private-sector collaboration with the AV industry will this strategy truly succeed in Texas.

Exhibit 22 provides an illustration of the AV Infrastructure, Connected Signing, and Data strategy that was previously discussed in the FNTOP Strategies and Conceptual Framework Report.
3.2 Description of ConOps Essential Features, Capabilities, and Functions

This section describes the proposed system and improvements, based on the components identified herein. The descriptions are provided at a high-level, indicating the operational features and functionalities without specifying design details or technology-specific solutions. The main features and functions of the AV Infrastructure, Connected Signing, and Data strategy are discussed in Exhibit 23, with a demonstration of features that address specific user needs applicable to this strategy as shown in Exhibit 21.

Exhibit 23: Automated Vehicle Infrastructure, Connected Signing, and Data Features and Functions

<table>
<thead>
<tr>
<th>Features</th>
<th>Main Functions</th>
<th>User Need(s) Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Proprietary Digital Map Database</td>
<td>AV vendors would be able to access a digitized map of the Texas roadway environment as a</td>
<td>UN-T4, UN-A10, UN-A11, UN-C2,</td>
</tr>
<tr>
<td>Features</td>
<td>Main Functions</td>
<td>User Need(s) Addressed</td>
</tr>
<tr>
<td>--------------------------------</td>
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<td>--------------------------------------------</td>
</tr>
<tr>
<td>Digital Map Update Capabilities</td>
<td>Permitted users, such as TxDOT, construction contractors, and AV vendors, would be able to contribute mapping data, such as LiDAR surveys done through construction projects or general survey. Users could also automatically contribute improvements, such as updated environments detected by the AV equipment (e.g., a new sign has gone up at ‘x’ location, witnessed crashes, asset conditions), which would be subject to verification or crowd-sourced confirmation.</td>
<td>UN-T4, UN-T7, UN-C2, UN-C4, UN-C5, UN-C9</td>
</tr>
<tr>
<td>Real-Time Notifications from Connected Infrastructure</td>
<td>Location and message information to support AVs in assessing the regulatory, warning, and other signing along a route would be broadcasted through V2I transceivers. ITS assets, such as DMS would broadcast notifications, advisories, or other messages via V2I to AVs to help support operational awareness.</td>
<td>UN-T3, UN-T4, UN-T5, UN-T7, UN-A3, UN-C1, UN-C2, UN-C4, UN-C5, UN-I5</td>
</tr>
<tr>
<td>Facilitate Future Improvements for TMFN</td>
<td>This system will facilitate a stronger AV ecosystem in Texas as Level 4 AVs are tested and enhanced. A stronger ecosystem will shorten development time, allowing additional traffic management benefits to be captured in the future.</td>
<td>UN-T9, UN-C3, UN-C7, UN-I2, UN-I11</td>
</tr>
</tbody>
</table>

Since this system relies on technological processes, the general framework follows the requirements for a successful ITS program. At a high level, a successful ITS program requires 1.) a means to collect data, 2.) a means to process the data, and 3.) a means to distribute that data to the targeted user group. As long as this process is followed, this system will have the necessary building blocks to succeed.
The following sections examine several key processes to consider as part of the AV Infrastructure, Connected Signing, and Data strategy. The intent is not to define one approach as the sole approach for all components, but rather outline the key characteristics so that a given approach can be correctly applied to a situation. The following processes are discussed in the following sections:

- **Data Collection** – Includes airborne and ground-based LiDAR surveys, vehicle communications to transmit recommended map updates, Advanced Traveler Information System (ATIS), and AV environmental detection system;
- **Data Processing** – Includes non-proprietary digital map database, trusted API connectivity, advanced data processing system, proprietary digital map database, AV vendor processing component, and ATMS CV module component; and
- **Information Distribution** – Includes connected signing/RSUs, vehicle communications to receive digital maps, and ATIS.

### 3.2.1 Data Collection

Data collection methods for this system aim to collect information regarding:

1. Permanent roadway infrastructure;
2. Temporary roadway infrastructure (e.g., work zones, lane closures);
3. Real-time traffic conditions;
4. Roadway incidents; and
5. Needed roadway improvements (e.g., pothole detection, worn lane striping, damaged guardrail).

Various components to support some or all of these information elements are discussed in the following sections. These components are conceptual in order to illustrate certain general ideas, but other options could feasibly serve the same role.

#### 3.2.1.1 Airborne and Ground-based LiDAR Surveys

TxDOT occasionally uses airborne LiDAR surveys for terrain modeling, which involves a laser imaging scan done from a helicopter, or ground-based LiDAR, an automated collection of data by reflector-less laser which involves high density scanning of an object or location to collect a “point cloud” of data points. The point cloud of data is further processed into a three-dimensional computer model image. Typically done from a remote instrument location or multiple locations, three-dimensional laser scanning is especially good for sites or objects
that are difficult to access, have high traffic volumes, involve extreme detail, or have other extreme dangers or conditions associated.

This method has also been utilized in place of conventional topographic or digital terrain model (DTM) surveying with much success, especially where high traffic volumes or lane closure issues (safety) were critical factors. Presently, the accuracy of the scanned data is said to equal or even exceed that of conventional survey methods, even electronic total station work, with the additional advantage of a greater number of data points all throughout the structure or project.17

The introduction of unmanned aerial devices or vehicles would be an additional channel of airborne LiDAR surveys.

3.2.1.2 Vehicle Communications to Transmit Recommended Map Updates

This component would allow AVs to transmit all relevant map-related data to the hosted digital map database. This would generally include any updates to the mapping environment that were logged by the AV, as well as any issues encountered at a particular geocoordinate on the roadway (e.g., a pothole). This component may also send current traffic information, based on the observations of local conditions made by the AV’s onboard systems. It is likely that this communication would rely on a stable high-bandwidth service, such as cellular or Wi-Fi, as opposed to sending updates over RSUs.

3.2.1.3 Advanced Traveler Information System

DriveTexas is a source of traveler information already collected and disseminated by TxDOT that can be used to inform the non-proprietary digital map database. DriveTexas receives data feeds from LoneStar ATMS and HCRS, which gets translated into actionable information before it is published on DriveTexas. At a statewide level, this data can include road and lane closures, current and planned construction projects, ice/snow conditions, traffic conditions and delays, rest area locations, traveler information centers, and information regarding special events. Additional details are available in Section 2.2.9 and 2.2.10.

3.2.1.4 Automated Vehicle Environmental Detection System

This component would transmit environmental surveys gathered in real-time by each AV’s on-board sensors to the AV vendor’s proprietary, centralized digitized map repository. This mapped data could include environmental characteristics such as road topology, signing, and traffic conditions observed at the location. This component would be responsible for determining what information regarding the roadway environment requires the attention of TxDOT (e.g., potholes, crash reconstruction, location of occluded signs and worn lane markings). This component is the responsibility of each AV vendor (not TxDOT), but TxDOT

would provide a capability to link to any data processing components to which they would be willing to contribute data.

### 3.2.2 Data Processing

Data processing methods for this system aim to process information to determine:

1. Whether the non-proprietary digital map database needs to be updated;
2. Which elements of the non-proprietary digital map database need to be updated;
3. Whether the private-sector proprietary digital map database needs to be updated;
4. Which elements of the private-sector proprietary digital map database need to be updated;
5. What messages/notifications need to be broadcasted for each connected sign or infrastructure;
6. What messages/notifications need to be transmitted to TxDOT regarding infrastructure or other issues; and
7. What action needs to be taken based on the data received.

Various components to support some or all of these information elements are discussed in the following sections. These components are conceptual in order to illustrate certain general ideas, but other options could feasibly serve the same role.

#### 3.2.2.1 Non-Proprietary Digital Map Database

This component would serve as the data storage mechanism for the various data sources listed above and would involve a database containing a digitized map of the Texas environment. It would be available as a service—hosted either by TxDOT or another public or private entity, or hosted separately in the cloud—to all AV vendors to help them facilitate operations within the state by providing a consistent and up-to-date basemap of the Texas roadway network. This digitized map would require standardization for all parties, such as through a standards group like ISO, and be non-proprietary in nature to maintain competitiveness among AV users. It would be updated as the road environment changes, either through LiDAR surveys conducted by the State or through crowd-sourced LiDAR scans or AV-sourced map updates by the AV vendors themselves. TxDOT would populate the mapping database with data collected through construction projects and general surveys. The TxDOT Roadway Inventory described in Section 2.2.3 would likely be the starting point to make sure the non-proprietary digital map database covers the full Texas network in its final form, likely starting on the Interstates and expanding—through local partners—to the complete system.

#### 3.2.2.2 Trusted API Connectivity

This type of component would provide a clearly defined, publicly available API that would allow approved AV vendors/startups to transmit differences in the roadway environment
detected by environmental surveys gathered in real-time by each AV’s on-board sensors to TxDOT’s non-proprietary, centralized digitized map repository. Differences detected by AVs’ environmental detection systems may include characteristics such as new roadway geometries, potholes, worn lane markings, occluded roadway signs, work zones, etc. Through publicly available and publicly accepted protocols, this component would allow AVs to transmit real-time observations of traffic operations at a given location (e.g., witnessed crashes), based on their sensor reads of the environment that meet certain pre-agreed to data quality standards. It could also permit other trusted digital map developers to contribute data, such as independent groups doing LiDAR surveys on or near public roads.

This type of component would also allow approved AV vendors/startups to access TxDOT’s non-proprietary, digitized map repository as a service. AV vendors could request sections of the map based on where the AV is located and compare the non-proprietary map with the AV vendor’s proprietary map to determine whether there are any map elements that have been updated or added by TxDOT (e.g., location of temporary construction or work zones).

3.2.2.3 Advanced Data Processing System
This component would serve as the “brain” of the non-proprietary digital map database. It would be used for decision-making regarding validation of API requests to send or receive digital map data. Before sending the requested data, the advanced data processing system would validate approved AV vendors. This component would only ingest data from third-party sources subject to TxDOT concurrence or through crowd-sourced confirmation.

3.2.2.4 Proprietary Digital Map Database
Each AV OEM/startup maintains their own proprietary digital map database, which is used by each AV to understand its precise positioning and provide contextual awareness of its environment. The algorithms developed by each AV vendor that instruct AVs on how to react in each roadway situation may differ from vendor to vendor. This component is the responsibility of each AV vendor (not TxDOT).

3.2.2.5 AV Vendor Processing Component
Currently, each AV vendor with digitized mapping utilizes proprietary mapping software. In order to determine whether the vendors’ proprietary digital maps need to be updated (e.g., to reflect a temporary construction zone, regulatory information, etc.) and which elements need to be updated, this component will compare their map against TxDOT’s non-proprietary digital map database. This component would also need to determine how the AV should proceed, given the roadway features in the proprietary digital map database. This component is the responsibility of each AV vendor (not TxDOT), and it is assumed that it would consume public non-proprietary data in a manner that is agreeable to its operation.
3.2.2.6 ATMS Connected Vehicle Module Component
The ATMS collects and processes raw traffic data in real-time, allowing TMC operators to monitor, detect, and respond to planned and unplanned events. ATMS platforms used at each TxDOT TMC are discussed in Section 2.2.8. In this component, the CV module would be modified to translate operator instruction for roadside messaging into a digitized format that can be recognized by CV-equipped AVs. The component would add no workload to the operator, but rather translate the message into a digital language that may include MUTCD codes, geographic segments of impact, and other information as dictated by the message. When this custom message is sent out to a DMS, any associated RSUs would be able to broadcast the message for AVs that are operating in the area.

3.2.3 Information Distribution
Information distribution for this system aims to distribute information that would help AVs:

1. Receive a standardized, near real-time basemap of the Texas roadway environment;
2. Ensure that complex environments, such as construction zones, are accurately represented in the non-proprietary digital map database;
3. Add clarity on the local roadway environment for elements that are intuitive to human drivers, but not necessarily AVs (e.g., safety messages, MUTCD codes, or other regulations); and
4. Provide traveler information to AVs and non-AVs alike.

These components are conceptual in order to illustrate certain general ideas, but other options could feasibly serve the same role.

3.2.3.1 Connected Signing/Roadside Units
This component provides vehicle communications from roadside infrastructure—such as static signs, DMS (described in more detail in Section 2.2.5), or traffic signals—to vehicle OBUs. RSUs engage with the OBUs of vehicles to issue alerts regarding traffic information and other relevant travel data using V2I communications. In the context of this system, RSUs would broadcast messages containing sign codes, allowing for advanced awareness of the upcoming sign and provide more resolute information in the event that the sign was damaged, occluded, or destroyed – although AVs may still need to visually confirm the sign before taking action, having awareness of a sign that “should” be there may eventually offer aid in its decision-making. RSUs on DMS would likely follow the traditional CV RSU deployment, but with modified messaging to help clarify custom messaging to a machine. Under this component, connected DMS would transmit digital message equivalents to AV trucks, including but not limited to, lane closures, queuing information, and travel times. Much of this data is collected by traffic sensors, Weigh-in-Motion (WIM) and permanent count stations along the THFN. Connected DMS would also broadcast the message type to
AV trucks, allowing them to differentiate between public safety messages, traveler information, incidents, or other types of information.

For static signing, these RSUs may be modified in scale to be more passive—instead of receiving updates from TxDOT, they might simply broadcast the MUTCD code and/or other important message information, along with a geographic coordinate and applicable travel direction, to serve as navigational aids in the field.

Some traffic signals in the industry are utilizing CV technology to broadcast Signal Phase and Timing (SPaT) data to CVs. In addition to SPaT data, RSUs on traffic signals could also transmit other map-based infrastructure data. This data can help improve the efficiency of AV operations as trucks approach intersections. Increasing CV equipment at traffic signals also opens up possibilities for truck signal priority systems, which would further improve efficiency on the THFN.

This component will utilize the latest adopted communication standards in the transportation industry that are also adopted by the AV industry, which may include the CV applications standard (among DSRC, C-V2X, other later adopted protocols, or a hybrid of each) or more traditional sources like Bluetooth, radio-frequency identification (RFID), Wi-Fi, or others.

3.2.3.2 Vehicle Communications to Receive Digital Maps
This type of component would allow AVs to receive updated map information from either the non-proprietary digital map database or, depending on the AV operator, from the proprietary digital map database that has internally been updated from information from TxDOT. These maps would be loaded onto the AV itself to provide it a recent map of the operational environment. Given the anticipated size of the digital file, this data would likely be received by the AV through an over-the-air update from a high-speed cellular network or Wi-Fi.

3.2.3.3 Advanced Traveler Information System
DriveTexas will continue to serve as the online, public-facing database that provides real-time highway conditions throughout Texas for the general public (AVs and non-AVs). Some information shared from AVs, such as asset conditions (e.g., potholes), may be reported through DriveTexas to aid other motorists.

3.3 Conceptual High-Level System Architecture
Exhibit 24 illustrates the proposed high-level architecture of the advanced data processing system, which represents the primary component that makes the system work. When data requests or data contributions are received, the advanced data processing system would first validate the origin of the request to ensure that it comes from an authorized source. Data contributions from AVs’ environmental detection systems, CV OBUs, or other detection equipment, would be processed through a verification module to confirm that it is a trusted
contribution, and then evaluated against crowd-sourced information and other confirmation steps to determine if a change is warranted. If an update is required in the non-proprietary digital map database, the update will go through data translation as needed, before it modifies the database.

Data requests, such as digitized message equivalents of DMS messages to be posted by TMC operators, would go through the data translation module. The data translation module supports translations from human understood formats to digital AV format and vice versa. MUTCD codes on static signs would likely be coded in the field device itself and work locally with CV-equipped vehicles.

Exhibit 25—later in the document—illustrates the full system, which includes the components and the advanced data processing system.

**Exhibit 24: Advanced Data Processing System High-Level Architecture**

3.4 **System-Level Operational Environment and Processes**

Exhibit 25 illustrates how the various systems involved in the AV Infrastructure, Connected Signing, and Data strategy are interconnected with the systems operated by TxDOT, AV
vendors, and the end-users themselves. The non-proprietary digital map database—regardless if hosted by TxDOT or a third-party service—would be supported by an advanced data processing system that would validate API requests to send or receive digital map data and translate collected data into a clear digitized map environment used by AVs. TxDOT vehicles would conduct LiDAR surveys that would feed into the advanced data processing system to provide data for the non-proprietary digital map database. TxDOT’s ATIS, DriveTexas, would also provide data feeds from existing ITS assets to the advanced data processing system.

TxDOT Districts would be have responsibility over the ITS assets, including the connected infrastructure, although this responsibility (in terms of ownership, operations, and maintenance) may be collaborated with the TxDOT Division that is leading the strategy. TMC operators would be in charge of managing the messaging on DMS deployed on Texas roadways within their jurisdictions. Static roadside signs may have passive RSU equipment for messaging, which would be counted as part of the TxDOT ITS program. Actionable traveler information would continue to be shared from the ATMS to the ATIS for the general traveling public (i.e., drivers of AVs or non-AVs alike). In addition, the ATMS used at each TMC would request digitized messaging equivalents from the advanced data processing system through a new CV module to be broadcasted from each connected sign/RSU to CVs on the roadways.

AV vendors would access the non-proprietary digital map database through a trusted API connection and compare the contents with their own proprietary digital map database, if used. AVs on the roadway would get updates to their onboard maps from either the non-proprietary digital map database or their vendor’s proprietary digital map on an occasional basis, such as at the start of the trip when Wi-Fi is available or on an hourly basis over the cellular network, depending on data speeds. Any differences observed by AVs’ environmental detection systems, CV OBUs, or other detection equipment would be communicated back to the advanced data processing system at some point in the future, likely when near a high-speed wireless communication access point like a Wi-Fi hotspot. The advanced data processing system would run through its verification algorithms to confirm that this is a trusted source, and then evaluate the data against crowd-sourced information and other confirmation steps to determine if a change is warranted.

Exhibit 26 diagrams the information flows from the identified data sources to the conceptualized strategy. The end-users associated with the strategy are identified in the diagram, as well as the dissemination methods to provide digitized AV information to help facilitate AV operations within the State.
Exhibit 25: Systems Diagram for the AV Infrastructure, Connected Signing, and Data Strategy

Advanced Traffic Management Systems

Connected Vehicle Module

Connected Infrastructure

Non-Proprietary Digital Map Database

Advanced Data Processing System

Proprietary Digital Map Database and Automated Driving System

Unmanned Aerial Vehicles

Autonomous Vehicle Environmental Detection System

Connected Vehicle On-Board Units

Non-Autonomous Vehicles

TxDOT Vehicle LIDAR Data

Advanced Traveler Information System

TxDOT

Non-Proprietary Digital Map Environment

Autonomous Vehicle OEMs/Startups

Traveling Public

Existing System

New System

61
Exhibit 26: Data Flow Diagram for the AV Infrastructure, Connected Signing, and Data Strategy

Users
- TxDOT
- Connected and Autonomous Vehicles and Trucks
- TMC Operators
- Autonomous Vehicle OEMs/startups

Data Sources
- Airborne and Ground-based Lidar Surveys: Three-dimensional representation of the roadway network (e.g., permanent and temporary roadway structures)
- Vehicle Communications: Updates to the mapping environment that were logged by the AV, issues encountered at specific geocoordinates (e.g., potholes), current traffic information
- Advanced Traveler Information System: Road and lane closures, current and planned construction projects, ice/snow conditions, traffic conditions and delays, rest area locations, travel information centers, and information regarding special events

System Concept
- Non-Proprietary Digital Map Database and Advanced Data Processing System

Dissemination Methods
- Connected Signing/Roadside Units
- Vehicle Communications
- Advanced Traveler Information System
3.5 Support Environment
This section identifies major elements in the IT environment that would support this strategy. The expected resources (e.g., hardware, software, networking and business processes, etc.) are described as follows:

- Application services and interfaces to manage the broadcasting of information through connected infrastructure would reside in the new CV subsystem in keeping with the modular structure of the ATMS platform. TMC application servers and ATMS software clients would be hosted on the Districts’ local and wide area networks.

- Dynamic connected signs would retrieve the message from the existing ATMS DMS subsystem that TMC operators currently use to input messages to be posted and request the digitized message equivalent from the new advanced data processing system through the new ATMS CV module. The ATMS CV module would then broadcast the digitized message from the appropriate RSUs, without requiring involvement from the TMC operator.

- The new advanced data processing system would require API protocols to exchange requests, responses, and messages with other subsystems and applications.

- User security would be administered using the security features in the advanced data processing system. TMC operators, other ATMS users, and authorized AV vendors would be assigned accounts and password protected access in accordance with existing IT security policies and procedures that are applicable to the IT environment where the map is managed - either TxDOT or a third-party service provider. Security credentialing would need to be determined, such as using blockchain or other methods at the time of deployment.

- If the map database is hosted by TxDOT, TxDOT IT administrators would maintain servers, applications, and networks associated with the operation of the new advanced data processing system. Preventative maintenance would be performed at scheduled intervals and technical support would be provided to system operators and other users in accordance with organizational IT policies and procedures.

- Tools and methods to secure data in the non-proprietary digital map database, such as encryption, would be used in accordance with enterprise IT policies for information security.

- The Traffic Safety Division would support system development efforts to set up communication channels between the new advanced data processing system and the ATMS. If the mapping database is hosted by TxDOT, the Traffic Safety Division—in collaboration with other Divisions leading this strategy—would utilize systems engineering processes to manage software development, testing, and roll-out of updates and enhancements to the ATMS, advanced data processing system, and non-proprietary digital map database. The Traffic Safety Division would publish device
standards and specifications to support project development and procurement, similar to how standards and specifications are published as part of the current ITS program.

- District personnel would likely have some responsibility for maintaining and troubleshooting issues affecting the connected infrastructure deployed within their jurisdiction, depending on arrangements made with the Divisions leading the strategy.
4.0 Benefits, Impacts, and Alternatives of the AV Infrastructure, Connected Signing, and Data System

The purpose of this section is to identify the benefits and impacts that come with deploying this strategy. This section also identifies alternative options to this strategy and notes their respective drawbacks relative to the strategy proposed in this ConOps.

4.1 Benefits

This subsection summarizes some of the key benefits that TxDOT should expect from deployment of this strategy. From a benefits perspective, the implementation of this strategy would have the following impacts:

- **Increased Efficiency and Safety along Freight Corridors** – The ability to allow automated trucks and other automated vehicles to provide and use supplemental information regarding their environment would benefit the freight community by helping their onboard systems better recognize the environment. This would help connected and automated trucks operate more efficiently and safely, particularly in complex areas where advanced notification of atypical geometric design or customized regulatory information would be advantageous.

- **Aid in OS/OW Route Identification** – The non-proprietary digital map database could aid in OS/OW route identification, which would help improve the efficiency of TxDMV’s CMV permit distribution, as well as the safety of OS/OW vehicles.

- **Improved Asset Management** – The availability of data that can be collected from the multitude of automated trucks and vehicles on Texas roadways once AV adoption expands would help TxDOT compile a more comprehensive dataset on asset condition, including data points on location and severity of potholes, inconsistent pavement striping, faded roadway signs, vertical and horizontal clearance, and other issues. In addition, passive CV RSUs installed on signs could aid with asset management by making it easier for TxDOT to be able to inventory the number of signs in their roadways and compare what’s missing from previous inventories.

- **Increased Situational Awareness of AV Operators** – Notifications to AVs displayed on DMS would require minimal TMC operator involvement – they would utilize the same processes to display messages on DMS – but AV operators would benefit from increased situational awareness by having a machine-ready message automatically broadcast as part of that message.

- **Reduction of Level 3 and Level 4 “Disengagements”** – AV “disengagements” caused by AV misinterpretation of roadway infrastructure, signage, lane markings, or temporary messaging would decrease as a result of the enhanced information provided by this strategy. A standardized non-proprietary digital map database and associated roadside signs could offer navigable information regarding work zones,
lane closures, incidents, and other types of atypical conditions collected through crowd-sourced information.

- **Support for AV Operations and Development** – By helping Level 4 AV operators gain more experience on Texas roadways, it is expected that they will reach Level 5 autonomy with greater success in the future, which would have many good implications for freight transportation safety, mobility, and economic competitiveness in Texas. Working with AV vendors to develop this operational environment would help improve the “training” of algorithms to manage complex environments that would be managed under Level 5 autonomy. Achieving a more reliable AV operation would get these vehicles into widespread commercial operation, helping fill the gaps of freight movement that exist due to a shortage of long-haul truck drivers.

4.2 Impacts
This subsection describes the impacts that TxDOT and its stakeholders should expect as a result of the strategy’s deployment. First, impacts to the operational and institutional policies and constraints are highlighted, which TxDOT should review as part of the planning process for this strategy. Then it highlights the operational and organizational impacts that TxDOT should expect during deployment, as well as any impacts incurred as part of development. Lastly, it documents expected impacts to the stakeholder groups identified earlier in Section 2.4.

4.2.1 Policies
The following summarizes some of the key operational and institutional policies for system development:

- **Traffic Management** – The system shall be consistent with TxDOT Standard Operating Procedures (SOP) for TMC activities and tasks. The system must not interfere with the operations of the TMC, and operator involvement must be minimal, such as to infrequently confirm that the components are all online or converting non-standard DMS messaging to comprehensible messaging for AVs.

- **Data Sharing** – The system will comply with TxDOT agreements for sharing data with AV vendors/startups.

- **Data Security and Privacy** – The system will comply with any legal requirements for the protection, security, and privacy of data provided by and shared with stakeholders during system development, testing, and implementation. The system will not compromise any personally identifiable information (PII).

- **Operational Uptime** – Any system investment should be in operation 24 hours per day, seven days a week, 365 days per year, as time spent offline will decrease the user’s perceived value of the system. The system must utilize equipment that can fail in isolation so as to not take the entire system offline for a minor outage.
Compliance with Communication Standards – This strategy will utilize the latest adopted communication standards in the transportation industry that are also adopted by the AV industry, which may include the CV applications standard (among DSRC, C-V2X, other later adopted protocols, or a hybrid of each) or more traditional sources like Bluetooth, RFID, Wi-Fi, or others.

Digital Mapping Standards – The system shall require third-party data providers to adhere to the digital mapping standards set forth by an approved standards commission, such as ISO, who would standardize the mapping format through collaboration with DOTs and the AV stakeholders.

Data Latency and Reliability – The system shall provide data from the non-proprietary digital map database on a timely basis to support AV decision-making, and should be available at all times. Environmental updates from AVs to the non-proprietary map database also need to be provided in a timely manner. If the system is not responsive (e.g., connection not available), the data can be queued for update at a later time, depending on the type of update.

Data Quality – TxDOT shall ensure that the non-proprietary digital map database is updated on a regular basis and accurately reflects the Texas roadway environment. The system shall also implement a series of data checks to validate that the data comes from an authorized source and is confirmed by additional sources before the map is altered.

Limited Liability – TxDOT, AV operators, and any other party using this map will need to work out a limited liability agreement for offering updates. Map updates need to be viewed as an assistive service to aid in navigation, but the AVs themselves will need to be able to operate safely on their own should that map not be available.

4.2.2 Constraints
The following summarizes some of the key operational constraints for system development:

Budget Constraints – Funding is limited, which means a full-measure solution may not be attainable at the initial deployment. Additional funds will be necessary to expand the system beyond the initial deployment.

Maintenance – The system will include ITS hardware that will need maintenance and replacement. This will require TxDOT staff or a TxDOT-funded maintenance contractor to dedicate time for system upkeep, as well as for receiving the necessary training.

Limited ITS Deployment – ITS assets, such as connected signs/RSUs, will be used to broadcast digitized messages to AVs. It is likely that these devices will be first deployed along strategic freight corridors. TxDOT will need to educate the AV community as to which corridors have been equipped so that they do not have the expectation that digitized messages are available throughout the state.
▪ **Willingness to Share Data** – The robustness of the non-proprietary digital map database is in part dependent on crowd-sourced updates from AVs on the road. If AV vendors are not willing to share data with TxDOT, this strategy will be less effective. Vendors may not want to share mapping data if it gives them a competitive advantage. This may also apply to concerns about liability, such as sharing information when an AV “sees” a crash occur through its sensors.

▪ **Ability to Agree on a Digitized Mapping Standard** – As with most emerging technologies, standardization of data may not be achieved right away. TxDOT and its affiliated AV stakeholders can follow best practices to develop a recommended digitized mapping standard for adoption by a standards organization to serve as their non-proprietary map. As technology processes advance, updates may be required to the mapping standard or format of information, which would require investment in updates from TxDOT and its AV stakeholders.

▪ **ATMS Integration** – Processing components for this system are not currently integrated into the ATMS platform. TMC operators must be able to view the status and messages from connected infrastructure, or information reported from AVs within the ATMS console, and access details to determine when and where the notification was triggered.

4.2.3 **Operational Impacts**

From an operational perspective, the implementation of this strategy would have the following impacts:

▪ **New Training Requirements** – Maintenance personnel would require additional training in order to support the new connected infrastructure. TMC operators would require additional training to manage the new connected infrastructure. If TxDOT manages a non-proprietary digital map database, IT maintenance staff would need additional training to maintain a high-capacity server and communications network.

▪ **New Maintenance Requirements** – Maintenance personnel would need to dedicate resources to upkeep of any TxDOT-hosted digital map database and all associated with data storage. This may require experienced personnel who are familiar with database management requirements.

4.2.4 **Organizational Impacts**

From an organizational perspective, the implementation of this strategy would impact both the public and the private sector.

4.2.4.1 **Public Sector**

▪ **Reduced Dependence on Citizen Complaints to Find Infrastructure Issues** – Allowing the AV operators to automatically report infrastructure issues with limited liability could allow for crowd-sourced identification of areas that need repair or investigation.
- **Reduced Survey Costs** – The potential for digitizing high-resolution topographic information could reduce TxDOT survey costs and allow for quick lookups of bridge heights, road widths, and other geometric data for OS/OW permit reviews.

- **Reduced Infrastructure Expansion Costs** – TxDOT would experience cost savings by taking a Transportation Systems Management & Operations (TSMO) approach to increasing safety and operational throughput by facilitating use of advanced AV technology instead of adding capacity through highway expansions.

- **Potential for Increased Data for Crash Safety Analysis and Enforcement** – Upon witnessing a crash in real-time, AV LiDAR data could potentially be used to aid in crash reconstruction. This solution would likely require regulations to absolve the AV vendor of any affiliated liability of providing this data. Having this type of high-resolution crash data could help better interpret how crashes unfolded and result in more accurate crash reporting. TxDOT could share information captured by the system to assist TxDPS with investigations on violators and offenders. This could improve cost recovery for infrastructure repairs, which is usually borne by taxpayers instead of the vehicle drivers or owners.

- **Opportunity to Expand Strategy Across Texas** – If TxDOT adopts this strategy, it would demonstrate the successes and lessons learned to other public sector agencies, such as counties, cities, and other road managers. This demonstration would help facilitate adoption of this strategy on the entire Texas roadway network, as well as show the successes and lessons learned to other states that might be looking to accomplish similar AV goals.

- **Increased Collaboration Opportunities between Public and Private Sectors** – In order for the strategy to be effective, close collaboration between public sector agencies (i.e., TxDOT and regional agencies) and private sector companies (i.e., TxDOT and AV OEMs/startups) would be required. Collaboration should begin as part of the planning for this strategy, prior to any design decisions or deployments. An increase in collaboration opportunities would allow TxDOT to remain fully engaged in designing a roadway environment of the future, as well as help facilitate an AV ecosystem in Texas.

- **Updated SOPs that Institutionalize Additional Responsibilities** – Updated SOPs are needed to clearly lay out the roles and responsibilities as related to the new advanced data processing system and non-proprietary digital map database, regardless of whether it is TxDOT or a third-party service provider that hosts and operates this service. Agreements should be made regarding responsibilities for operating and maintaining these systems, including defining the new functionality introduced in regional TMCs’ ATMSs to manage connected infrastructure.
4.2.4.2 Private Sector

- **Facilitates a Common Framework for AV Operations** – Currently, AV operations differ for each OEM/startup, as each company utilizes proprietary mapping software and self-driving technology. The non-proprietary digital map database could be the basis for a common framework for AV operations across vendors and state lines through the use of consistent, standardized, multistate maps. Smaller AV start-up firms would have a greater advantage in finding a footing by not having to gather extensive mapping information or “learn from the ground up” on how to navigate construction zones. Altogether, this could help streamline development efforts and accelerate deployment of AV technology.

- **Decreased Dependence on Human Safety Drivers** – Level 4 AVs still require human safety drivers behind the wheel to take over driving in certain circumstances. In order for AVs to eventually achieve Level 5 automation, AVs need to gain experience at Level 4 to sort through unfamiliar problems. It is possible that Level 5 AV trucks may still require humans on board in order to assist with loading and unloading cargo, but it is possible that they may not be required to assist with driving functionality. Having a public non-proprietary digital map database would level the barriers of entry and accelerate testing and operations of Level 4 to gain that experience. Achieving a more reliable AV operation would get these vehicles into widespread commercial operation, helping fill the gaps of freight movement that exist due to a shortage of long-haul truck drivers.

- **Increased Collaboration Opportunities between Public and Private Sectors** – In order for the strategy to be effective, close collaboration between public sector agencies (i.e., TxDOT and regional agencies) and private sector companies (i.e., TxDOT and AV OEMs/startups) would be required. Collaboration should begin as part of the planning for this strategy, prior to any design decisions or deployments, so that private sector operators can contribute their insights to the public investment to support AV operations. An increase in collaboration opportunities would allow AV vendors in Texas to remain fully engaged in designing a roadway environment that accommodates their systems.

4.2.5 Impacts During Development
The development of this strategy is not expected to disrupt the operations of any static or dynamic signing currently deployed on Texas roads. A new CV module will need to be added to each ATMS platform to provide TMC operators with the tools to manage connected infrastructure. Custom software would be needed to develop data transfer protocols between the new advanced data processing system and the ATMS platforms so that digital message equivalents can be requested by the ATMS and then disseminated through connected infrastructure. System development is not expected to disrupt day-to-day TMC operations. Using the systems engineering process as the planning and development framework, ATMS updates could be developed and released iteratively with acceptance test
plans and procedures in place to verify that releases meet all requirements before system cutover to the production environment.

During implementation, TxDOT will need to conduct testing with multiple AV vendors to ensure that the LiDAR and CV data collected are stored correctly and that the non-proprietary digital map database produces information that is transmitted in a timely manner and interpretable by each automated driving system. Once this strategy is deployed, there will be a period of time where AV vendors will test the communication protocols with TxDOT before turning any or all operations over to a Level 4 AV.

### 4.2.6 Impacts to Stakeholders

Relevant stakeholders for the AV Infrastructure, Connected Signing, and Data strategy are listed in Exhibit 27. Stakeholders are denoted by roles of owner, key stakeholder, and/or end-user. TxDOT would work with AV stakeholders to establish best practices and standards for pursuing this strategy. Private sector AV companies will be key stakeholders to help inform this strategy as it is developed. End-users will include truck operators with partial or fully automated systems that would use the strategy components.

**Exhibit 27: Relevant Stakeholders for the Automated Vehicle Infrastructure, Connected Signing, and Data strategy**

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Role</th>
<th>Strategy Impact</th>
</tr>
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</table>
| TxDOT Division(s) | Owner/Key Stakeholder | • Will identify the Division to manage and fund the strategy. Will collaborate with other Divisions who might lead this effort.  
• Will develop the strategy and identify funding needs for capital and O&M.  
• Will help guide and recommend strategic placement of these systems, based on strategic planning criteria.  
• Will update the non-proprietary digital map database as geometries and work zones change.  
• Will support project implementation by developing standards and specifications for ITS devices and system components.  
• Will ensure that the placement of ITS are safe and consistent with national and Texas standards.  
• Will support ATMS development efforts to integrate the new strategy components by establishing statewide requirements. |
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<tr>
<th>Stakeholder</th>
<th>Role</th>
<th>Strategy Impact</th>
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</table>
| TxDOT Districts              | Owner/Key Stakeholder       | • Will support project implementation by developing standards and specifications for foundational capabilities required to support CAV deployments.  
• Will collaborate with Districts regarding ownership, operation, and maintenance requirements associated with any technological field deployments.  
• Will allocate TxDOT funds and pursue Federal grant opportunities to help transform technological solutions from concept to construction.  
• Will collect and analyze crash data from AVs and use it to inform the design and planning process. |
| Traffic Management Centers   | Key Stakeholder/End-User     | • Will collaborate with Divisions regarding ownership, operation, and maintenance requirements associated with any technological field deployments, such as connected signing/RUs.  
• Will help identify potential areas that could serve as good corridors for piloting this strategy. |
| Texas Department of Public Safety | End-User                  | • May utilize AV LiDAR data and other AV-sourced information to aid in crash reconstruction.                                                                                                                        |
| Texas Department of Motor Vehicles | End-User                  | • Will help identify how the availability of digitized maps could aid in identifying vertical and horizontal clearance concerns as well as their OS/OW route selections or other programs.  
• May utilize—if beneficial—digitized maps to screen OS/OW routes for recent issues as part of the permit process. |
| OEMs/Startups                | Key Stakeholder/End-User    | • Will help inform possible needs, gaps, and solutions in this strategy that could help improve the safety, |


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<tr>
<th>Stakeholder</th>
<th>Role</th>
<th>Strategy Impact</th>
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<tbody>
<tr>
<td></td>
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<td>efficiency, mobility, and longevity of their AV operations.</td>
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<td></td>
<td></td>
<td>• Will compare their proprietary digital map database with the non-proprietary digital map database and update their map as necessary.</td>
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<tr>
<td></td>
<td></td>
<td>• Will utilize their technology to report the observed environment to the non-proprietary digital map database for potential updates.</td>
</tr>
<tr>
<td>Automated Trucks</td>
<td>End-User</td>
<td>• Vehicles with partial or full AV features would operate along corridors where this strategy has been deployed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Will share LiDAR data from AVs with AV vendors.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Will receive information from connected infrastructure broadcasts and send back to AV vendors to process.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Will broadcast vehicle speed, location, and trajectory information to TxDOT AV infrastructure.</td>
</tr>
<tr>
<td>Other Users</td>
<td>End-User</td>
<td>• Other AVs will receive the same benefits as AV trucks, with the same ability to receive information from and send information to both the non-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>proprietary digital map database (subject to being an authorized AV vendor) and connected infrastructure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Non-AVs would benefit from crowd-sourced insights collected from AVs and distributed via traditional traveler information channels.</td>
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</tbody>
</table>

4.3 **Alternatives To This Strategy**

This proposed ConOps for this strategy comes with many benefits and impacts, but it inherently comes with prerequisite requirements in order to be successful in the long-term. While it meets the goals and objectives defined in the FNTOP strategy, it is not the only option available. This subsection identifies the inherent disadvantages and limitations of this strategy, and then contrasts the strategy against candidate alternatives that would also satisfy the intent, but were rejected due to being less advantageous.

4.3.1 **Disadvantages and Limitations**

The strategy in this ConOps is expected to have several disadvantages and limitations, which form prerequisite requirements that TxDOT will need to satisfy for it to fully succeed.
Unlike the policy and constraint considerations identified earlier, these disadvantages and limitations will need to be continuously addressed.

- **May Require a Pilot Program** – This strategy aims to implement a solution that is fairly visionary and may require a pilot program before widespread deployment can be achieved. A pilot program would help determine the benefits that can be achieved through the adoption of a mapping standard in conjunction with the deployment of passive CV RSUs. It would also help begin establishing cultural adoption by AV operators and help TxDOT prepare to manage the significant amounts of data required by this strategy.

- **System Development, Operations, and Maintenance May be Costly** – New hardware and software would be needed to implement the advanced data processing system and non-proprietary digital map database. Additional equipment would also need to be operated by the TMC and maintained regularly. Newly deployed connected infrastructure would require wireless communications to transmit data back to the ATMS, if it doesn’t already exist. All of these factors would increase overall ITS programmatic O&M costs.

- **Data Processing and Storage Needs May be Extensive** – The amount of data storage needed to maintain a Texas-sized three-dimensional digital map may exceed what TxDOT servers or third-party service providers can currently handle. On top of that, AVs could generate from five terabytes to 32 terabytes of data per day.\(^\text{18}\) The processing power needed to extract the useful information from the rest of the “noise” may require more data processing power than TxDOT or third-party service providers can currently handle.

- **Limited Geographic Coverage May Stunt Adoption Rates at First** – Not every part of the THFN would be instrumented with connected infrastructure at first. Deployments would be done strategically, focused first on critical freight corridors. This may somewhat stunt adoption of these tools until lesser traveled roadways implement this strategy over time.

- **Compliance with Digital Messages is Necessary** – The system is only effective if AV trucks and other AVs heed the messages broadcasted by connected infrastructure. In addition, if AVs report infrastructure assets that are in poor condition, but TxDOT does not conduct the necessary maintenance, then there may be no improvements in overall traveler experience or safety, and the private sector’s opinion on the strategy and the data they are submitting to it may be negatively impacted.

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AV Vendor Policies and Privacy Concerns May Prohibit Data Sharing – The system may be limited by AV vendors’ willingness to share AV data with TxDOT, which would limit the full capabilities of the system.

4.3.2 Alternatives and Tradeoffs Considered
Given the above disadvantages and limitations, alternative options and tradeoffs were examined in lieu of the strategy in its proposed form. The alternative options listed below explore different approaches to improving AV operations. It is important to note that some of these alternatives may seem intuitively nonsensical, but they are worth noting to confirm that all options have been explored and rejected for the stated reasons.

4.3.2.1 Alternative 1: “Do Nothing” Approach
This alternative would maintain the current situation, which would require no changes to the existing program, no increase in costs, and no additional staff. TxDOT’s existing traffic operations program would continue to provide the same types of service, with no traveler information tailored for AVs or CVs. Messages for the traveling public would be shared via DMS and DriveTexas, as they are currently. Technology advancement would fall under the responsibility of AV vendors to achieve Level 5 automation.

This alternative is not recommended because it maintains the same shortcomings of the current situation, capturing none of the benefits outlined in Section 4.1.

4.3.2.2 Alternative 2: Eliminate Connected Infrastructure Strategy Elements
This alternative would reduce the scope of the strategy to just the deployment of the advanced data processing system and non-proprietary digital map database. This alternative would still provide access to a consistent, standardized digital basemap for AV vendors and allow them to report discrepancies in permanent or temporary roadway infrastructure detected in their proprietary digital maps. However, AVs would lose the benefits of advanced awareness of upcoming signs or explanation of an unclear message.

This alternative is not recommended because while TxDOT would expect to see some reductions in overall costs, they would also see reductions in efficiency and safety along freight corridors as a result of decreased information sharing between TxDOT and AV vendors.

4.3.2.3 Alternative 3: Eliminate Advanced Data Processing System and Non-Proprietary Digital Map Database Strategy Elements
This alternative would reduce the scope of the strategy to just the connected infrastructure and addition of the CV module in the ATMS. This alternative would help AVs navigate complex roadway situations and allow them to report assets in poor condition, but make them rely on their proprietary digital maps along with DriveTexas for planned construction zones and lane closures.
This alternative is not recommended because while TxDOT would expect to see significant reductions in overall costs, they would also see reductions in efficiency and safety along freight corridors as a result of decreased information sharing between TxDOT and AV vendors.

4.3.2.4 Alternative 4: Use Different Technology Solutions
This alternative would retain the original scope of the strategy, but would apply a different technology solution to the connected signage component. For example, instead of using V2I communications for broadcasting static sign and DMS messaging, an alternative option of using quick response (QR) codes that are scanned by trucks may be selected instead. QR codes are more cost effective compared to RSUs and can also be visually interpreted by AVs. However, as the size of the message increases, so does the size of the QR code and the complexity of the image. This limits the amount of information that can be shared digitally, and would also monopolize space on DMS that are used for traditional messaging. In addition, complex QR codes may require more pixels per square inch than DMS can support.

This alternative is not recommended because while TxDOT would expect to see some reductions in overall costs, they would also see reductions in the flexibility of the solution with a technology that may not age well. Additionally, many of the limitations of existing standard signs (e.g., loss of visibility during inclement weather, loss of message when defaced, etc.) would apply with QR codes.

4.3.2.5 Alternative 5: Use an AV Vendor’s Digital Map
This alternative would release TxDOT from ownership of the non-proprietary digital map database. Since AV vendors already maintain their own proprietary digital maps, TxDOT may opt to partner with one AV vendor and utilize their digital map as the official basemap for the state of Texas, similar to other sole-source procurements.

This alternative is not recommended because while TxDOT would expect to see significant reductions in overall costs, it would come at the expense of no longer having a AV technology-agnostic solution, which could hinder development of other AV vendors in this space. In addition, TxDOT may be subject to their AV partner’s business goals and objectives.
5.0 Operational Scenarios

This section presents six operational scenarios that describe situations in which this strategy could significantly improve the safety, mobility, and efficiency of AV operations on the THFN. Each operational scenario describes the users involved and the issues that are intended to be addressed, as well as the outcomes or benefits the users are expected to experience through the deployment of this strategy. The following operational scenarios do not address all of the improvements, nor do they represent a comprehensive set of use cases, but rather they demonstrate some of the key situations that this system could help serve and improve. Exhibit 28 summarizes the operational scenarios presented in this section.

Exhibit 28: Summary of Operational Scenarios

<table>
<thead>
<tr>
<th>#</th>
<th>Scenario</th>
<th>FNTOP Stakeholders Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Urban Work Zone</td>
<td>Trucker</td>
</tr>
<tr>
<td>2</td>
<td>AV Operations on a New Route</td>
<td>Dispatcher, Truckers</td>
</tr>
<tr>
<td>3</td>
<td>Non-Proprietary Digital Map Database Geometric Update</td>
<td>TxDOT, AV Vendors</td>
</tr>
<tr>
<td>4</td>
<td>Connected Sign – Static Sign</td>
<td>Trucker</td>
</tr>
<tr>
<td>5</td>
<td>Connected ITS – Dynamic Sign</td>
<td>Trucker</td>
</tr>
<tr>
<td>6</td>
<td>Issue Reporting</td>
<td>TMC Operator, Highway Patrol, Trucker</td>
</tr>
</tbody>
</table>

5.1 Urban Work Zone

David is a safety engineer at an AV technology startup. He has been involved in testing Level 4 automated trucks throughout Texas for over a year. Having previously been a long-haul truck driver, he is very familiar with the trucking industry. David enjoys his job, especially the fact that he is able to experience AV technology firsthand.

It is currently 10 a.m. on a Wednesday. David and a designated human driver are making a delivery from Dallas to Houston while testing a Level 4 AV truck. They are currently traveling southbound towards Houston on I-45, which is a pre-mapped route that the AV truck has traveled before. Even though the AV truck must utilize its onboard equipment to monitor the environment, the digital map aids in understanding that environment. David is monitoring the truck’s system in real-time, ensuring that it is interpreting the environment around it correctly and adjusting its speed accordingly. David’s human driver is ready to assume control at any moment if the truck cannot successfully evaluate the environment.

A few minutes later, David notices an orange “Road Work Ahead” sign on the road ahead, followed directly by a “Reduced Speed Ahead” sign. They are approaching a major work zone...
on the southbound lanes. David recalls hearing about this work zone on the news. TxDOT is reconstructing a major bridge and the lanes have been shifted substantially to accommodate traffic. David realizes that—at their current state of testing—the AV truck often cannot figure out what to do in construction zones. Work zone contractors often place barrels at varying gaps, fail to stripe consistently, and have signing that is often inconsistent. Even though TxDOT’s resident engineers have been trying to enforce consistency, there are simply too many more critical things for those resident engineers to be reviewing than barrel spacing. As such, David does not know if the AV truck will understand its environment, which will likely cause a “disengagement” where the human driver takes control again.

However, to David’s surprise, he watches as the AV truck’s software evaluates the situation and recognizes how to navigate through the construction zone. Prior to their departure from Dallas, TxDOT had conducted a LiDAR survey of the construction zone to identify how the work zone was operating. TxDOT had uploaded that data to the non-proprietary digital map database as an update, which was then made available to all AV vendors. Several AVs had recently downloaded the map and navigated successfully through the construction zone, uploading any additional updates on the map to the non-proprietary digital map database once they completed their trip and were within Wi-Fi range. Prior to David’s departure from Dallas, his AV truck had downloaded the most recent map update over Wi-Fi, so it has a verified record of how to interpret and navigate through the construction zone.

As they drive through the active work zone, David monitors the truck’s system for any other issues it may encounter. He notices that the truck’s onboard algorithms are challenged by the work zone environment, but the digital map allows them to recognize things better. Additionally, his truck is collecting all information on what it sees in the work zone, and will upload these observations to the non-proprietary digital map database once they arrive in Houston. David realizes that their contributions will aid other AVs that come after him, as well as provide any relevant geometric information to TxDOT, such as potholes and lanes that are too narrow.

5.2 AV Operations on a New Route
Rick works as a dispatcher for a trucking company in Texas that delivers cargo shipments between large cities in the state. His company has joined with an AV technology company that has instrumented several of Rick’s trucks with onboard AV equipment. The AV technology company is testing and refining Level 4 autonomy, even though they maintain both a human driver and a safety engineer in the cab. The goal is to eventually operate the truck without a driver. Rick enjoys seeing technology in use, and regularly uses this AV truck to move cargo while in testing.

It is a Tuesday morning around 10 a.m. and Rick is planning the routes for the afternoon. It is an extremely busy day and many of his trucks are committed to other shipments. A large delivery is scheduled to depart from Austin to Houston at 2 p.m. At this time, only the AV
truck is available to move the shipment. The AV truck requires a proprietary digital basemap to aid in its navigation from origin to destination, which requires the AV company to pre-map the route using LiDAR and other electronic survey equipment. The Houston-Austin link has been mapped along I-10 to I-35 previously, but today I-10 has several major lane closures due to road construction and extremely long delays. Rick prefers that the AV truck use U.S. 290 as an alternate route, which will save at least three hours of travel time between the two cities, but U.S. 290 is not part of the AV company’s pre-mapped routes at this time.

Fortunately, a non-proprietary digital map database standard has been approved by a standards organization, and TxDOT has developed a statewide digitized map. TxDOT’s goal is to collect and provide a digital map environment for all THFN roads. In this case, TxDOT has elected to host this map database. Although Rick’s AV partner has not mapped U.S. 290, a competitor AV operator has previously mapped the environment and made the digital information available to TxDOT. Additionally, TxDOT’s database includes LiDAR surveys of the roadway environment from various design projects that help affirm the accuracy of the U.S. 290 digital map. Rick realizes that the AV trucks in his company can also use U.S. 290 if they simply download and use the digital map.

Rick coordinates with the human driver and safety engineer who are picking up the load in Austin with the AV truck. The safety engineer downloads the U.S. 290 map from TxDOT’s website using a Wi-Fi connection; it takes some time, but the download is eventually complete. The AV’s internal verification processes evaluate the map and confirm that it appears to meet acceptable standards. The safety engineer notes that the AV still ultimately must navigate using its onboard equipment as if the map was not there, but having this digital map will help ensure the onboard computer has a better understanding of its environment. The AV truck is able to complete the Austin-Houston route along U.S. 290 without issue, and Rick continues to use the TxDOT digital maps to identify other alternative routes as they become available.

5.3 Non-Proprietary Digital Map Database Geometric Update
TxDOT has recently adopted and deployed a non-proprietary digital map database for AV operations, which aligns with standards adopted by the appropriate standards organizations for digital AV mapping. TxDOT and its partners have submitted an extensive mapping database of major THFN routes throughout Texas, with the number of covered miles growing each year.

AVs have been operating along U.S. 290 for several years, utilizing both TxDOT’s digital map and their own internal systems. On one segment of U.S. 290, TxDOT has implemented a new bypass, which expands the number of lanes on U.S. 290 for three miles and brings the highway up to the latest design standards. Since the bypass was built adjacent to the existing U.S. 290, no lane closures were needed and traffic continues to operate unimpeded. However, once the bypass is built, TxDOT immediately shifts all traffic to the
new bypass, essentially closing the old U.S. 290. While most human drivers find the new bypass to be much quicker, no AVs have yet used this route.

Recognizing that AVs have a presence on U.S. 290, TxDOT conducts a LiDAR survey of the new bypass prior to opening it to traffic. The LiDAR survey collects information on the geography and location of the road, as well as any obstacles that exist on the roadside (e.g., guardrail, sign posts, etc.). TxDOT immediately uploads the bypass’s LiDAR survey to the non-proprietary digital map database that is used by many AV firms who operate in Texas. By the time the bypass has opened to traffic, over half of the AV vendors in Texas have downloaded the map update and view it as a trusted source.

All AV operators still rely on their onboard equipment to navigate the U.S. 290 environment, although the digitized map helps enhance AV response. For AV vendors who have downloaded the updated map, their AV trucks successfully navigate the bypass with minimal issue. Their onboard equipment recognizes that the road’s geometrics are shifting to the bypass and their updated internal map conveys that this aligns with the new design.

For AV vendors who have not downloaded the updated map, their AV trucks have varying degrees of success. The onboard equipment for the trucks recognize that the road’s geometrics are shifting to the bypass and, given that onboard equipment is the primary navigation tool, the computer determines that the lanes are likely shifting. The computer recognizes that this deviates from its onboard map, which limits its understanding of why the road is different. Many AV trucks are able to navigate into the bypass without issue by following the geometrics; some AV trucks—typically those that are “less mature” than a Level 4 operation—are able to navigate to some degree, but may need to “disengage” if they encounter a scenario that they cannot determine the appropriate action given they do not have access to the new map. These trucks would pull off to the side of the road and note an issue to their dispatch, or alert their safety driver to take control in lieu of pulling off the road.

All AV trucks that navigate the bypass are able to send any suggested map updates to the TxDOT non-proprietary digital map database once they reach a Wi-Fi access point at their destination. These updates affirm that most of the map is accurate, and offer crowd-sourced insight on any unmapped issues that were not captured in the TxDOT map. The TxDOT system has validation protocols to determine what updates should be made. Once made, updated maps are sent out to AV trucks at a later time, and AV operations continue to become more efficient in Texas.

5.4 Connected Sign – Static Sign
On a Wednesday afternoon at 2 p.m., Dan is traveling eastbound on I-10 from San Antonio to Houston. He is a vehicle safety engineer for an AV technology company that is testing Level 4 automated trucks in the state of Texas, focusing on long-haul deliveries. He is
partnered with a human driver and is carrying a shipment to Houston as part of the test. Today is an average day for Dan as he monitors the AV truck’s software reports as it travels along an interstate environment. He has been overall impressed with the company’s automated trucks, especially their ability to interpret the environment using onboard sensor equipment. The few issues that Dan encounters are generally related to traffic operations, particularly when a new sign is installed that changes the operational condition (e.g., reduces speed limits) or when a new or existing sign is not completely visible to the AV.

A few miles down the road, Dan notices a new sign that TxDOT has recently installed. The sign indicates an upcoming reduced speed limit, which matches an MUTCD W3-5 Reduced Speed Ahead sign. TxDOT has installed this reduced speed limit as a pilot test case in response to a high rate of high-speed crashes over the next few miles. Dan realizes that his AV is not aware of this new speed restriction, but anticipates that the onboard sensors would read the sign and adjust accordingly. However, as he draws nearer, he realizes that the sign is partially blocked by a stalled truck on the shoulder. The AV’s onboard sensors capture brief glimpses of the sign, but the onboard computer’s algorithms cannot validate the sign. Occluded signs can be a major issue for AVs when there is no additional information indicating special driving instructions. When the AV truck is unable to interpret the entire sign, it may elect to ignore the sign or, in the worst case, revert control back to the driver.

However, Dan notices that as his truck passes the reduced speed limit sign it immediately takes corrective actions, even though his software does not log a validated “visual” confirmation of the sign. As he analyzes the vehicle’s log, he notices that his on-board CV transceivers received a V2I broadcast from the connected sign, providing the correct information on the type of sign and message. Dan realizes that TxDOT has been instrumenting many critical road signs with passive CV equipment that broadcasts information on operational conditions. While the AV truck could not fully validate the roadside sign due to the blocked sight line, the computer’s algorithms acknowledged receipt of the speed restriction from the sign’s passive CV equipment and, when coupled with partial reads of the sign, confirmed there was enough evidence to take corrective action.

This is the first time Dan has noticed his truck receiving a broadcast from a static sign, but he is impressed with how well his software handled the transaction. He realizes that receiving such broadcasts would help his AV recognize a changing condition in advance, even if no action is required until the sign is observed, which could aid in advanced braking or other corrective measures. Additionally, depending on what information can be published on the passive CV equipment, he realizes it could offer additional geometric guidance for the local environment, particularly in areas with atypical roadway geometries. This type of information will greatly aid his AV’s operation in the future.
5.5  Connected ITS – Dynamic Sign
Morgan is en-route to Dallas from Fort Worth, traveling eastbound on I-30. She is carrying a shipment from Fort Worth Alliance Airport to a distribution center outside of Dallas, but she is not doing any of the driving. She is serving as a human backup driver in a Level 4 automated truck that is being tested. Accompanied by a safety engineer who monitors the software, Morgan’s job is to be ready to take control if the AV truck’s computer cannot process the environment properly and elects—out of interest of safety—to “disengage” and pull off to the roadside.

Today is an average day for Morgan and her safety engineer. It’s a sunny Friday afternoon at 3 p.m. Traffic is flowing smoothly, there are not any active work zones, and she is on time to make the delivery. Approximately a half mile ahead, Morgan notices a DMS that is displaying a message “Dogs on Road Ahead. Proceed with Caution”. This is not a normal message, and Morgan’s safety engineer notes that their software—which makes decisions primarily from reading the environment and all associated signs—may not recognize such an atypical message. At that point, the AV truck will either take no action or elect to “disengage” for Morgan to take control.

However, as the AV truck approaches the DMS, the AV truck takes corrective action to slow down. Morgan and her safety engineer realize that the DMS has been equipped with a CV RSU that is broadcasting machine language information about the content of the message. This message—through its unique structure—conveys that “Dogs on Road Ahead” is a cautionary notification, similar to “object on road” or other standard terms that the computer is familiar with. Similarly, “Proceed with Caution” is another notification that recommends reduced speed, similar to a speed reduction. Any location-based information of where these dogs are located is included in the message, allowing the AV computer to pinpoint on its map where the problem is likely occurring. While this message is loaded with good pieces of information, most of it was automatically generated by TxDOT’s ATMS when the TMC operator had entered this custom message, selecting useful pieces of data as they constructed it to help clarify it to the AVs operating on the road. Even though Morgan’s truck still operates primarily using onboard equipment to monitor the environment, having recognition of this custom message allows it to take preventative action early to avoid being caught in a bad situation.

Morgan did not know that custom messages could be broadcasted to AV trucks and be successfully recognized. She is impressed with the successful outcome, which improved her trip. As she continues driving to her destination, she is curious to see how V2I broadcasts from other connected signs will be interpreted by her truck.

5.6  Issue Reporting
Danielle is an operator at the Houston TranStar TMC. She has worked at the TMC for approximately five years. She enjoys her job, as she feels she is able to assist in resolving
traffic incidents and keep traffic flowing efficiently. It’s currently 5 p.m. on a Wednesday. Although there’s heavy rush hour traffic leaving Houston, it is an average day for Danielle. Traffic is moving slowly, but luckily there are no traffic accidents causing further delays.

Danielle is aware that many AVs are operating in Texas, and—with the deployment of a non-proprietary digital map database—these AVs are able to report on roadway issues in a crowd-sourced fashion, offering good quality information. Today, Danielle notes that the ATMS is reporting a potential pothole on I-10. The ATMS regularly polls reports that come in for the non-proprietary digital map database and notes that, of 100 AVs that have traveled on the road recently, 95 of them have detected and reported what appears to be a pothole. The ATMS passes along this information as a “high likelihood” detection, meaning a pothole or some similar issue is likely present. Danielle contacts the TxDOT maintenance group and has a maintenance truck travel to the site. They confirm that, indeed, a major pothole is present and should be patched immediately.

Danielle knows that the AVs and their onboard detection equipment are providing TxDOT and partner agencies with a wealth of information. Last week, TxDMV requested digital map information from TxDOT regarding a low bridge underpass in the Houston area. They had intended to route an OS/OW permit below that bridge, but the digital map information immediately told them that—due to a recent resurfacing project that unknowingly raised the road elevation more than designed—the bridge is now too low and that they should identify another route. Even though TxDMV still requires the route to be driven before issuing an OS/OW permit, having the digital map available to confirm the low bridge status saves them from traveling the incorrect route and wasting time.

Similarly, Danielle recalls an incident that occurred last week where TxDOT AV information was useful. A human driver in a car collided with a stopped vehicle. The driver claimed that the stopped vehicle actually backed into him. An AV truck had been driving near the scene of the accident and its onboard sensors captured data useful to reconstructing the crash scene. While this type of data is not reported to the non-proprietary digital map database, the data sharing agreements and liability protections put in place between TxDOT and the AV community as part of this strategy made it possible for the AV vendor to provide the data that their onboard systems “observed” through LiDAR and other means. The state police used the data to help reconstruct the crash scene. While the AV data may not be admissible in court, it helped the officers identify other factors that they can review that proved the stopped vehicle did not back up.

Danielle knows that this wealth of data will help her job and the jobs of other public agencies. She looks forward to the potential of AVs to help improve operations in Texas.
6.0 Next Steps

This AV Infrastructure, Connected Signing, and Data ConOps is one of six ConOps documents being prepared as part of the FNTOP. As noted earlier, these six strategies were chosen through a selection process that vetted a total of 10 recommended strategies with key stakeholders. Each ConOps intends to further answer how each specific strategy would operate, which systems it would interface with, and how various user groups would be impacted by the introduction of the strategy. Based on this document, this strategy is ready for TxDOT to advance to implementation planning in the future, which would include the development of system requirements and high-level design (detailed further in the Implementation Plan as shown in Exhibit 29).

In addition to the ConOps development, the FNTOP is also developing an Implementation Plan that explores the near-, medium-, and long-term actions that will drive the successful implementation of the 10 FNTOP strategies. This will include an assessment of the readiness of each strategy. The goal is to inform the next steps beyond the FNTOP as these strategies are transitioned from planning to design. This will include outlining how the AV Infrastructure, Connected Signing, and Data strategy would ultimately come to fruition, utilizing insights provided as part of this ConOps.

Exhibit 29: Next Step in the Texas FNTOP
7.0 References

The following is a list of relevant documents, standards, and references used in preparing this document:

- Texas Department of Transportation, *Cooperative Automated Transportation Strategic Plan*, February 2020.