TTI: 0-7125

Potential Applications to Expand the Texas Connected Freight Corridors System

Technical Report 0-7125-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

sponsored by the
Federal Highway Administration and the
Texas Department of Transportation
https://tti.tamu.edu/documents/0-7125-R1.pdf

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-23/0-7125-R1		

4. Title and Subtitle POTENTIAL APPLICATIONS TO EXPAND THE TEXAS CONNECTED FREIGHT CORRIDORS SYSTEM	5. Report Date Published: December 2022 6. Performing Organization Code
7. Author(s) Nick Wood, Paul Anderson, Minh Le, Dan Middleton, Robert Saylor, and Jeffery Warner	8. Performing Organization Report No. Report 0-7125-R1
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-7125
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	13. Type of Report and Period Covered Technical Report: September 2021–August 2022 14. Sponsoring Agency Code

15. Supplementary Notes

Project sponsored by the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Expand Applications for Texas Connected Freight Corridor
URL: https://tti.tamu.edu/documents/0-7125-R1.pdf

16. Abstract

The Texas Connected Freight Corridors (TCFC) system is a connected vehicle (CV) environment that seeks to improve safety and mobility for the Texas Triangle, which consists of the Austin, Dallas/Fort Worth, Houston, San Antonio, and Laredo metropolitan regions. The TCFC project is a baseline effort to develop and deliver six initial applications for use by vehicle fleets. The applications selected for deployment include advanced travel information systems, queue warning, work zone warning, wrong-way driving, road weather warning, and freight signal priority. This project expands the initial TCFC system by considering additional CV applications for inclusion and consideration. Project activities included reviewing existing CV efforts and pursuits, surveying key private stakeholders operating within the TCFC system, assessing the effectiveness and financial feasibility, and outlining the next steps for procurement and implementation.

17. Key Words	18. Distribution Statement
CV, ATIS, truck parking	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia https://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	60	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Report 0-7125-R1
Project 0-7125
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Sponsored by the
Texas Department of Transportation
and the
Federal Highway Administration

Published: December 2022

TEXAS A&M TRANSPORTATION INSTITUTE
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DISCLAIMER

This research was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Nick Wood, P.E. #117258.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was sponsored by TxDOT and FHWA. The authors thank the TxDOT project manager, Tom Schwerdt and the TxDOT Project Monitoring Committee: Lei Bu, James Kuhr, Jianming Ma, and Casey Wells. The authors also thank Phillip Hempel, with TxDOT's Research and Technology Implementation Division, for participating in project meeting activities.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1 INTRODUCTION

BACKGROUND AND OBJECTIVES

The Texas Connected Freight Corridors (TCFC) system is a connected vehicle (CV) environment that seeks to improve safety and mobility for the Texas Triangle, consisting of the Austin, Dallas/Fort Worth, Houston, San Antonio, and Laredo metropolitan regions, as seen in Figure 1.

Source: TxDOT, 2022.

Figure 1. Texas Connected Freight Corridors System Physical Boundaries.

Through a private and public stakeholder process, 12 freight intelligent transportation systems (ITS) applications were prioritized and grouped into three tiers. Figure 2 shows the applications by tier. The prioritization process assisted in identifying the top applications to deploy given the available funding within the TCFC project.

Source: TxDOT, 2022.

Figure 2. Texas Connected Freight Corridors System Applications Selected for Deployment.

The objective of this project was to expand the initial TCFC system by considering additional CV applications for inclusion and consideration. Project activities included reviewing existing CV efforts and pursuits, surveying key stakeholders, assessing the effectiveness and financial feasibility, and outlining the next steps for procurement and implementation.

ORGANIZATION

The remaining chapters of this report include the following:

- **Chapter 2: Review and Case Studies**—This chapter investigates technologies listed in the Texas Department of Transportation (TxDOT) Freight Network Technology and Operations Plan (FNTOP) and provides a current review of various technologies, summarizing the location of planned and operating applications.
- **Chapter 3: Application Assessment**—This chapter investigates and assesses three selected applications.
- **Chapter 4: Implementation Framework for Next Steps**—This chapter develops an implementation framework for two selected applications.

CHAPTER 2 REVIEW AND CASE STUDIES

This chapter investigates technologies listed in TxDOT's FNTOP, published in December 2020, as well as an initial inquiry of private-sector automated trucking firms. In addition, it provides a current review of various technologies, summarizing the location of planned and operating applications. Some of the most promising applications for further consideration include truck parking availability (i.e., integrating current TxDOT efforts under the broad TCFC system) and advanced high-resolution traveler information systems (i.e., enhancing existing applications). The research team also attempted to coordinate private sector outreach with other Texas A&M Transportation Institute (TTI) staff working with the TxDOT Connected and Automated Vehicle (CAV) Task Force and CV deployments on I-30 in the Dallas/Fort Worth region.

FREIGHT TECHNOLOGIES

The FNTOP (Freight Planning Branch, 2020) identified and evaluated 12 strategies. This document briefly summarizes the motivation and scope of each strategy and its current status. The FNTOP advanced 10 of the 12 strategies and selected six for the concept of operations development. Some strategies or components thereof are already underway through other TxDOT initiatives. The research team noted examples of deployment, whether in Texas or elsewhere.

STRATEGIES

Automated Vehicle Infrastructure, Connected Signing, and Data

The current state-of-the-art for autonomous vehicles (AVs) relies on highly detailed digital maps, which include information about roadway geometry, navigational references, and rules such as speed limits. These maps need to be updated whenever roadway geometry or signage changes. In addition, these should be updated regularly to capture changes to navigational references (e.g., pavement markings, trees, buildings) that AVs use to locate themselves on the maps (Ort et al., 2018). AVs are programmed to disengage and request human intervention when roadway conditions or appearance differ substantially from the digital map (Joubert et al., 2020). A related issue is sign readability; AVs are trained to detect and read road signs but may struggle under certain lighting conditions or when the sign is obscured or damaged.

This strategy has two main components. The first is the development and hosting of a digital map for AVs. The strategy would consider different mechanisms for keeping this map up-to-date, including updates based on surveys, construction documents, and crowdsourced observations from AVs. The second is to equip road signs and ITS assets such as dynamic message signs (DMSs) for vehicle-to-infrastructure (V2I) communications to transmit location and messages to AVs. Together, these two components would help provide AVs with updated digital maps, ensure that road signs and DMS messages are being interpreted correctly by AVs, and provide AVs with many additional navigational aids.

This strategy was selected for the FNTOP Concept of Operations development (Freight Planning Branch, 2020). The typical digital map has not been deployed; currently, each AV company maintains its proprietary map (Wilken and Thomas, 2019; Joubert et al., 2020). Connected signs are the subject of ongoing research (Gozdecki et al., 2019) but have not been deployed. A related strategy is modifying conventional road signs for better machine readability. A research study covering Australia and New Zealand showed that current sign detection technology struggled to read DMSs and sometimes misread static signs (Roper et al., 2018). Roper et al. recommended several changes to sign design, sign placement, and DMS operation.

Binational Traffic Operations Center

Commercial motor vehicle (CMV) border crossings between the United States and Mexico have multiple steps, including tollbooths, customs, and weigh stations, that different agencies run. However, there is little to no real-time coordination at present, so differences in agency staffing levels or incidents can create bottlenecks and long queues. This strategy would create a virtual or physical traffic operations center (TOC) to share real-time information between Mexican customs, U.S. Customs and Border Protection (CBP), TxDOT, and the Texas Department of Public Safety (TxDPS). The strategy would also include ITS assets to collect data on border crossing times and queues, communicate crossing times and alternate routes to drivers, and expedite border inspections.

In the FNTOP, this strategy was deferred (i.e., better fulfills goals and objectives of other TxDOT initiatives). However, parts of this strategy have been deployed. For example, radio frequency identification (RFID) tag readers have been deployed at U.S.-Mexico border crossings, and current wait times are posted on public websites (Rajbhandari et al., 2009; Rajbhandari and Villa, 2011; *Border Crossing Information System—Real-Time Information*, n.d.).

Blocked Rail Crossing Traffic Management System

Highway-rail at-grade crossings can sometimes be blocked by long, slow-moving, or stopped trains for extended periods. Many drivers choose to re-route in such cases, especially when there is a grade-separated crossing nearby. Advance notification of blocked crossings and alternate routes would be particularly valuable for emergency responders, trucks, and drivers unfamiliar with the area and potential alternate routes. The strategy would install sensors at highway-rail at-grade crossings to detect when the crossing is occupied by a train and how long the gates are down. Sensors along the same rail line could be linked to forecasting upcoming crossings and archived for later analysis. The other component of the strategy is traveler information services, which could involve flashing beacons, dynamic message signs, V2I communications to alert connected vehicles, or some combination of these strategies.

This strategy was selected for the FNTOP Concept of Operations development. Flashing beacons and dynamic message signs connected to rail crossings have been deployed in many places, including Calgary (Bushman and Berthelot, 2005); Jackson, MS; Louisville, KY; Kirkwood, MO (*Using Traveler Information to Mitigate Blocked Rail-Highway Crossings*, 2018); and San Antonio (Carter et al., 2000). Additionally, field trials have been conducted in Lincoln, NE (Khattak and Lee, 2018). Signal preemption strategies have also been deployed in situations where the rail crossing blocks one approach when active (Venglar et al., 2000; Urbanik and Tanaka, 2017).

Centralized Data Repository for Freight Applications

Freight data is currently collected by a variety of public- and private-sector entities that each have their own systems for data management and policies for access and use. This atomization is a barrier to data sharing and applications that leverage different data sources. The strategy would create a new statewide freight data lake that would handle functions including collection, processing, storage, and sharing and standardize rules for access and privacy. In the FNTOP, this strategy was deferred (i.e., better fulfills goals and objectives of other TxDOT initiatives). However, similar centralized data repositories have been deployed in California (Tok et al., 2011) and at a regional level by the Delaware Valley Regional Planning Commission (*Developing PhillyFreightFinder*, 2017).

Freight Integrated Corridor Management

Many freight corridors in the state are heavily trafficked and experience congestion in recurring peak periods and from other causes, including construction, incidents, special events, etc. When congestion occurs, cars frequently divert onto frontage roads and other parallel routes. This option is more difficult for trucks due to restrictions on height, weight, or through truck traffic. In addition, alternate routes can be overwhelmed by the volume of detouring traffic during major incidents.

The strategy would deploy ITS technologies on major freight corridors and alternate routes. Specific components may include sensors on the freight corridor to detect congestion and the back of the queue, DMSs, or fixed travel time comparison signs to encourage the use of alternate routes and connected traffic signals on alternate routes. The traffic signals on alternate routes could implement freight signal priority or have unique timing plans that can be used when the route is part of an official detour.

In the FNTOP, this strategy was not prioritized. Integrated corridor management has been deployed in several places, including US 75 in Dallas, I-15 in San Diego, and I-210 in Los Angeles County, CA (Hardesty and Hatcher, 2019). A related strategy is active traffic management (ATM), including queue warning, dynamic re-routing, and traveler information components. Fuhs reviewed ATM deployments in the United States and Europe (2010).

Fiber Optic Cable System Statewide Expansion

In urban areas, many TxDOT roads are already equipped with fiber optic cables for ITS infrastructure or have fiber optic nearby. In rural areas, however, high-speed communication networks may not be available. Network capabilities are a limiting factor for rural ITS deployments: either projects have to factor in the cost of extending fiber optic cable from the nearest available location, or ITS functionality limits the bandwidth of alternatives such as 3G cellular. The strategy would deploy fiber optic cables along TxDOT right-of-way in connection with current or plans for ITS deployments. This strategy would explore opportunities to reduce costs by installing cables during unrelated construction projects, sharing network capacity with other users, and leasing conduit space to third-party telecommunications companies. In the FNTOP, this strategy was not prioritized. Several research studies have considered the potential and value of extending fiber optic cables along highways (Hess et al., 1988; Wilmot, 1995; Durairajan et al., 2015; Iyer et al., 2020).

High-Resolution Advanced Freight Traveler Information System

Truck dispatchers and drivers typically plan their routes. Still, drivers usually have the discretion to adjust the route based on real-time traffic conditions (with the notable exception of single-trip permits for oversize/overweight vehicles). Better-quality traffic data would help trucking companies to plan routes and help drivers re-route to avoid congestion and incidents. The strategy would deploy sensors and purchase third-party probe data along major freight corridors. These data would be fed into a centralized system made available to trucking companies in real-time. The centralized system could also include some analytic functions, for example, using artificial intelligence (AI) to detect incidents or future traffic conditions. This strategy was selected for the FNTOP Concept of Operations development. Previous TxDOT research has studied the benefits of implementing a truck-centric advanced travel information system (ATIS) in El Paso (Sharma et al., 2020).

Safety Warning Detection System

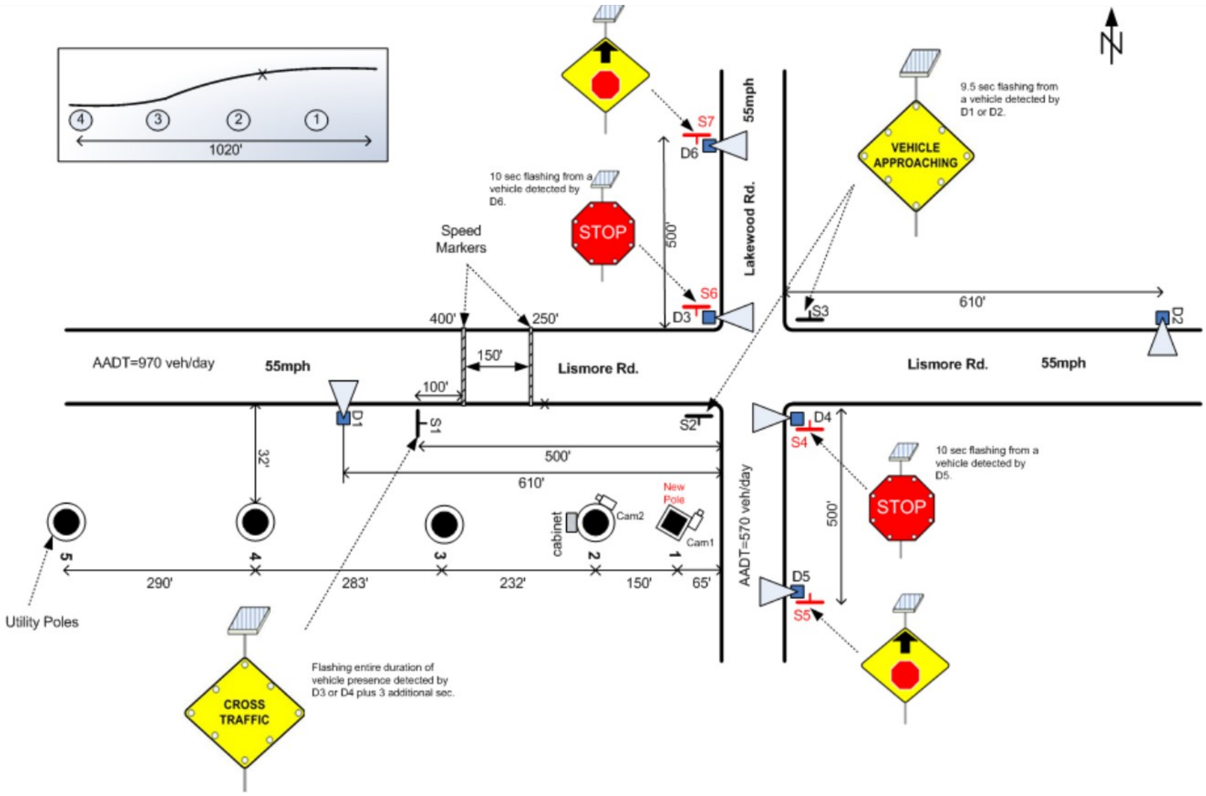
Crashes involving excessive speed and damage to infrastructure caused by trucks exceeding height or weight restrictions continue to be areas of concern. Static signs usually indicate rules such as speed limits, bridge clearances, and weight limits. However, truck drivers may ignore these signs, not see them in time, or, in rare cases, be unaware of the height of their vehicle (e.g., drivers of rented box trucks). Flashing beacons or other dynamic messaging may improve compliance with posted restrictions.

This strategy would involve installing sensors that trigger flashing beacons or other dynamic messages. Proposed use cases include:

- Weigh-in-motion sensors linked to a bridge weight limit. The sensor could activate signs instructing overweight trucks to take an alternate route.

- Overspeed detection that would activate signs that advise drivers to slow down to a posted speed limit or curve advisory speed.
- Intersection conflict warning would activate flashing beacons at unsignalized rural intersections when an opposing vehicle is crossing the road.
- Overheight warning, which would activate signs instructing overheight trucks to take an alternate route.

This strategy was selected for the FNTOP Concept of Operations development. Weigh-in-motion sensors are widely deployed to collect data and select trucks for weighing at static scales. Richardson et al. (2014) evaluated the accuracy of bridge weigh-in-motion and concluded that the accuracy was not sufficient for direct enforcement. For overspeed detection, vehicle-activated signs have been widely deployed (Winnett and Wheeler, 2003; Jomaa et al., 2017). A similar strategy is speed enforcement cameras, widely deployed in Europe but not common in the United States. Mountain et al. (2005) reviewed the effectiveness of different speed management strategies in the United Kingdom. Intersection conflict warning devices have been deployed in various locations, including Sweden (Lind, 2009), Virginia (Penney, 1999), Victoria, Australia (Bradshaw et al., 2013), Minnesota, see Figure 3 (Kwon & Ismail, 2014), and New Zealand (Mackie et al., 2017). Overheight detection and warning systems have been deployed in many places (Maghiar et al., 2017). For overheight detection, some deployments continue to struggle with driver compliance.



Source: Kwon & Ismail, 2014.

Figure 3. Intersection Conflict Warning Signs near Duluth, Minnesota.

A low railroad overpass in Durham, NC, has an overheight detection system that triggers a flashing "Overheight Must Turn" sign and a red phase at the upstream traffic signal but continues to have bridge strikes (WRAL, 2017; *11 FOOT 8—The Canopener Bridge*, n.d.). Figure 4 shows a screenshot from a YouTube video with the warning measures activated.

Source: yovo68, 2021.

Figure 4. Overheight Detection and Warning Measures in Durham, North Carolina.

The Sydney Harbour Tunnel in Australia has a system that projects a stop sign onto a water curtain, which can be activated for overheight vehicles and can close the tunnel in case of an incident (Nguyen and Brilakis, 2016). This system was developed and installed in response to a tunnel fire incident. Unfortunately, many drivers ignored other warnings and continued driving into the tunnel, increasing the incident's severity and duration (Laservision, 2015). Figure 5 shows the system in action.

Source: Laservision, 2015.

Figure 5. Stop Sign on Water Curtain, Sydney Harbour Tunnel.

Smart Freight Connector

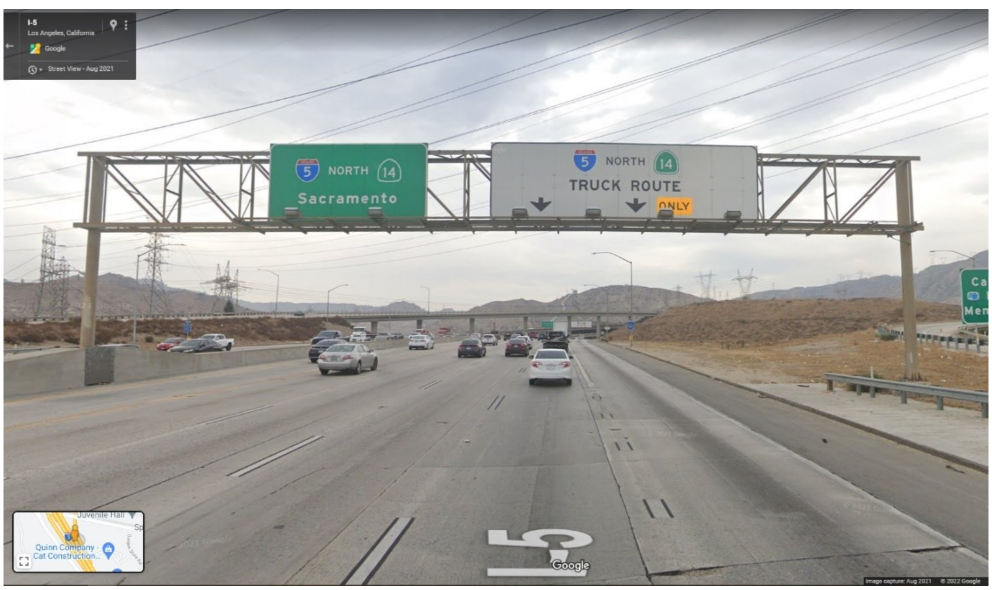
Many freight traffic generators, including intermodal facilities, industrial parks, distribution centers, and international border crossings, experience high traffic volumes and congestion. Some of these facilities also generate high demands for truck parking or staging areas as drivers wait for a scheduled delivery time or available loading dock.

The strategy involves several related measures to improve mobility around freight traffic generators. These may include:

- Freight signal priority and signal progression timed for key freight movements and vehicle performance (e.g., acceleration and cruising speed).
- Longer yellow intervals on freight corridors ensure that trucks do not face a yellow interval dilemma (i.e., not enough distance to stop or enough time to clear the intersection [Liu et al., 1996]).
- Truck-only lanes.
- Off-street staging areas for trucks.
- DMSs communicating travel times and parking availability.
- Integration with CV and ATIS deployments.

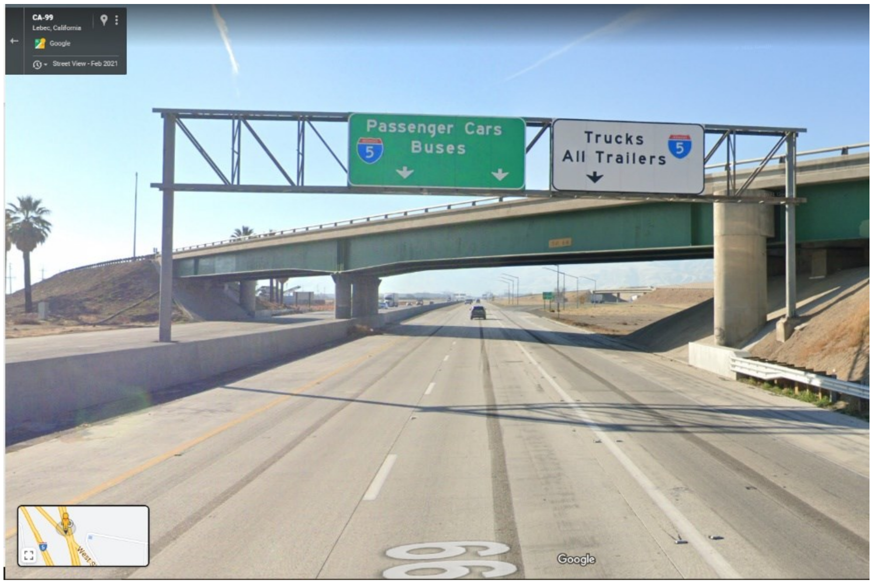
This strategy was selected for the FNTOP Concept of Operations development. Freight Signal Priority has not progressed to implementation, but recent research has evaluated its potential and discussed key considerations for deployment (Kaisar et al., 2020; Murshed et al., 2021). Research has recommended longer yellow and all-red intervals on traffic signal timing as truck percentage increases (Rakha et al., 2014).

Truck-only lanes have seen limited deployment, including on I-5 in California at the SR 14 and SR 99 interchanges (California, n.d.). The truck-only lanes at the I-5 and SR 14 interchange were implemented during a freeway widening project. Trucks follow the original alignment of I-5, while the car-only lanes were constructed on a new alignment. Trucks are required to use the truck-only lanes, which have an operational benefit by removing trucks from a weaving section between the I-210 and SR 14 interchanges and a safety benefit by separating trucks and cars on a steep grade. Figure 6 shows the signage in the northbound direction. The truck-only lanes at the I-5 and SR 99 interchange are only southbound. Truck-only lanes split from SR 99 and I-5, merge on a bypass facility, and then rejoin I-5 southbound downstream of the car lane merge. Figure 7 shows the signage on SR 99.



Source: Google StreetView.

Figure 6. Beginning of Truck-Only Lane, I-5 and SR 14 Interchange.



Source: Google StreetView.

Figure 7. Truck-Only Lane, SR 99 at I-5.

Broader deployments of truck-only lanes have been studied in Southern California (Fischer et al., 2003) and Atlanta, GA (Chu and Meyer, 2008). For more information on truck parking and ATIS, refer to the Truck Parking Availability System (TPAS) and High-Resolution Advanced Freight Traveler Information System (HRAFTIS) sections of this document.

Smart Work Zone Information System

Work zones typically have a reduced speed limit and may have additional restrictions on truck weight, width, height, or lane use. These restrictions may change throughout the construction project and sometimes vary by time of day (e.g., overnight lane closures). Therefore, trucks need to be aware of current restrictions if they need to take a different route and benefit from the knowledge of current traffic conditions.

The strategy would include several ITS and CV technologies such as queue detection and warning, speed monitoring, travel time measurements, incident detection, and overheight detection. The FNTOP listed this strategy as underway (other TxDOT initiatives). Smart work zone initiatives have been deployed in several states, including Arkansas (Tudor et al., 2003), Kansas, Nebraska, Iowa, Missouri (Meyer, 2000), and North Carolina (Bushman et al., 2004). Not all applications have focused on freight. Raddaoui and Ahmed (2020) studied the cognitive load and distraction potential of weather and work zone alerts on truck drivers in a driving simulator.

Statewide Traffic Operations Center

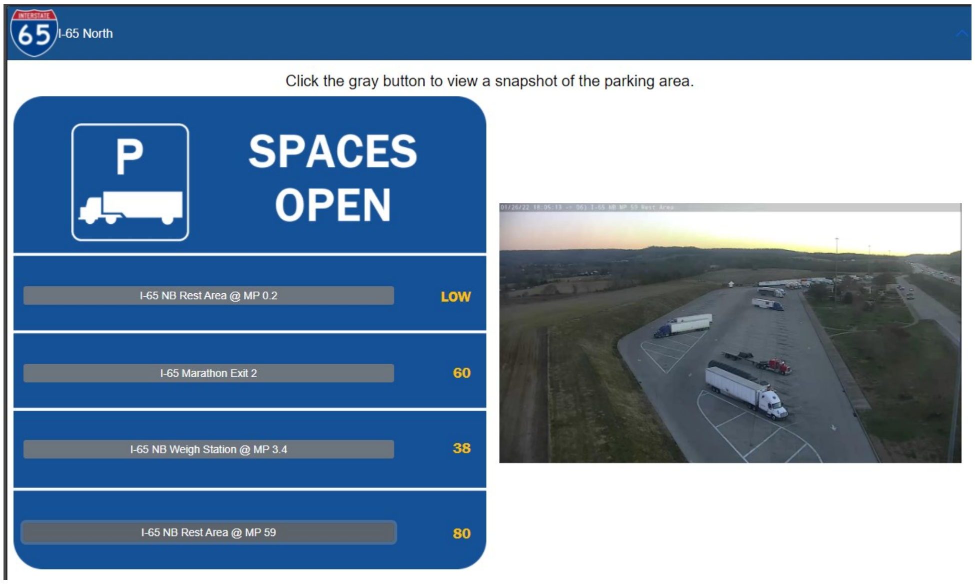
TxDOT roads located in urban areas are well-instrumented and monitored by regional traffic management centers (TMCs). Some urban districts have ITS assets on major corridors outside their core urbanized area. However, there is little coordination between regional TMCs, and many rural areas of the state are not instrumented and monitored from a traffic operations standpoint.

The strategy would establish a statewide traffic operations center (STOC). In normal conditions, the STOC would exchange data with regional TMCs, develop statewide DMS messages, and monitor rural roads outside the scope of regional TMCs. During major incidents (e.g., route closure, hurricane evacuation), the STOC could assist a regional TMC or direct larger-scale strategies across multiple districts. This strategy was selected for the FNTOP Concept of Operations development. A statewide traffic operations center exists in Delaware (Faghri et al., 2021), Wisconsin (Federal Highway Administration, 2014), and Wyoming (Alfelor and Garcia, 2016). Bejleri et al. (2020) reviewed incident information sharing practices in Florida and recommended a similar information exchange hub.

Truck Parking Availability System

Demand for truck parking has increased significantly during recent years due to a general increase in truck traffic and stricter enforcement of rest periods via electronic logging devices. In addition, many rest areas fill up entirely at night, causing trucks to park in unauthorized locations such as shoulders and ramps. The strategy would install sensors at public rest areas to monitor the number of available truck parking spaces. Information about truck parking availability would be communicated via roadside signs and made available in a shared data feed that drivers could access via DriveTexas™, third-party apps, and their company's truck management system.

The FNTOP listed this strategy as underway (other TxDOT initiatives). Truck parking availability systems have been deployed in a pilot or full implementation in Maryland (Haghani et al., 2013), Indiana, Iowa, Kentucky, Michigan, Minnesota, Ohio, Wisconsin, Kansas (Moore et al., 2019; WTAD3x, n.d.), and on IH-45 in Walker County, Texas (TTI, 2021). Figure 8 shows a screenshot of Kentucky's truck parking website.



Source: TRIMARC Truck Parking, n.d.

Figure 8. Truck Parking Availability Website, Kentucky.

PRIVATE SECTOR OUTREACH

As part of the review, the research team conducted semi-structured interviews with private-sector automated trucking firms to better gauge interest in expanding the number of applications and geographic extent of the TCFC system. Ongoing engagement with the private sector is a success factor due to the emerging nature of the technologies and new issues and concerns, such as new business markets and enhanced technological capabilities.

The research team contacted representatives from at least eight automated trucking firms. The selection of the representatives occurred in concert with efforts from researchers involved with the TxDOT CAV Task Force. Identification focused on staff with title names that incorporated government affairs, public policy, and business development elements. The research team hypothesized that staff better versed in policy and business might better address high-level technology questions. Next, the research team sent e-mail messages to the private trucking firms with a list of questions and a one-page summary of the TCFC project. Respondents could either provide a reply as an e-mail or through a follow-up conference call.

The semi-structured interview questions were straightforward and designed to elicit an enabling answer from the respondents. The specific questions included the following:

- Has your organization heard of the Texas Connected Freight Corridors (TCFC) project?
    - *For those agencies that are active partners of the TCFC project, this question was asked instead: Your organization is a partner of the Texas Connected Freight Corridors (TCFC) project. How do you plan to be involved?*

- Do any of the current applications suit your organizations' business needs? We currently have truck signal priority, queue warning, work zone warning, road weather warning, wrong-way driving, and advanced travel information systems that plan to launch later this year.
- Initially, we did not select CV applications related to truck parking availability, low bridge height warning, emergency electronic brake light warning, eco-dynamic routing, pedestrian warning, and border wait times. Do any of these applications incite interest from your organization?
- What applications would you like to see included as part of the TCFC system?
- What other enhancements or modifications to the TCFC system would incentivize participation in it?

Three of the eight automated trucking firms responded to the initial inquiry made by the research team. Of the three, one firm answered all the questions, and the remaining two stated they would reply to the research team after further internal consultation. A major issue with getting respondents to react was the dramatic staff turnover rate for the trucking firms. Many personnel listed with the TxDOT CAV Task Force transitioned to new roles at other organizations during the fall months of 2021. The research team conducted an internet search for potential new respondents as a corrective measure. However, many of the respondents were fresh in their role and getting authorization to speak to the research team resulted in delays in getting information.

The firm that did provide a complete response was already engaged as a partner with the TCFC project. The firm approaches technology by relying primarily on its systems and using TxDOT and other sources as secondary information. Their business model does not look favorably on saying, "Our systems failed because TxDOT did not provide data." So, any additional data or application can only augment current systems. The respondent plans to use the TCFC system and its integration with equipped on-board units and modified electronic logging devices (ELDs) to support their self-driving solutions. Of the existing applications, the respondent looked favorably on the work zone warning system by providing detailed information on the location and extent of lane closures. The respondent also stressed the need to update work zone information regularly as lane closures often occur every day or even within specific periods. Freight signal priority was not a priority for the company since most of their business occurred on limited-access highways. Adding applications that addressed truck parking availability seemed to generate the most interest from the private trucking firm, mainly if the parking lots could accommodate automated trucking. The firm also replied favorably to the idea of expanding the TCFC westward in Texas on I-10 and I-20, where considerable automated trucking currently operates.

CHAPTER 3 APPLICATION ASSESSMENT

This chapter investigates and assesses three selected applications from Chapter 2:

- Truck Parking Availability System (or integrating current TxDOT efforts under the broad TCFC system).
- High-Resolution Advanced Freight Information System.
- Binational Traffic Operations Center.

The research team selected the Truck Parking Availability System because it ranked high within the FNTOP. In addition, TPAS incorporates existing projects such as the I-10 Corridor Coalition Truck Parking System and the TxDOT Connected Work Zone Project. The research team also selected the HRAFTIS application because of the relative ease of enhancing an existing TCFC application with greater capabilities. The FNTOP deferred the Binational TOC strategy for further development as part of the TCFC initiative. But the Binational TOC is currently under investigation as part of other initiatives at TxDOT, such as the Statewide TOC strategy. As such, the research team included it here because of the uniqueness of border and security issues relative to commercial truck traffic entering the United States/Texas. The research team assessed each application based on its practicality, benefit/cost factors, relationship with CV adoption rate, and level of innovation.

TRUCK PARKING AVAILABILITY SYSTEM

Practicality

The FNTOP characterizes the scope of TPAS as:

- Instrument in public state rest areas (SRAs) with detection technology to monitor real-time truck parking availability.
- Implement a processing and evaluation platform (TxDOT Advanced Traffic Management System [ATMS] or third-party software) for processing field truck parking data into usable information.
- Publish real-time truck parking availability data on roadside signs at key decision points to help truckers decide where to park.
- Utilize a public data feed to make truck parking availability data available to other systems and groups, such as DriveTexas™, private sector truck parking apps, and freight companies' truck management systems.
- Store availability and utilization data in a database to support future freight planning projects and studies.

The Texas Statewide Truck Parking Study (TxDOT, 2020a), completed in early 2020, led to strong momentum for implementing TPAS, coupled with the I-10 TPAS Advanced

Transportation and Congestion Management Technologies Deployment grant. The assessment from the research team builds on those efforts through a focused benefit/cost (BC) analysis of the recommended priority sites.

Benefit/Cost Factors

The recent TxDOT Texas Statewide Truck Parking Study identified 76 sites as high-priority based on capacity, safety needs, and freight network significance (TxDOT, 2020b). In addition, the study found if TPAS should be expanded, upgraded, or repurposed for truck parking based on reviews of the sites. The report subdivided the sites into Primary (a total of 34) and Secondary (a total of 42) sites. Primary sites consisted of existing picnic area/pull-off, SRA, or traveler information centers with potential upgrades for truck parking infrastructure. Whereas secondary sites mainly consisted of opportunity sites that were closed or TxDOT facilities that were closing and could be repurposed for truck parking. Weigh stations were also considered, in coordination with TxDPS.

The research team focused only on the primary sites for the assessment and used available data from the Texas Statewide Truck Parking Study and the Federal Highway Administration (FHWA) Tool for Operations Benefit/Cost (TOPS-BC) tool. The TOPS-BC is a sketch-planning level decision support tool developed by the FHWA Office of Operations. It is a macro-enabled spreadsheet tool for estimating the lifecycle cost of many commonly used Transportation Systems Management and Operations (TSMO) strategies. For the analysis, sites were divided into two groups; one with 20 or fewer parking spaces, and one with more than 20 spaces.

Table 1 and Table 2 show the different benefits and cost assumptions used. In addition, each strategy is simplified to a few key parameters, many of which have default values that were comparable to the I-10 ATCMTD TPAS Grant estimates.

Table 1. Customized TOPS-BC Inputs for Truck Parking and Reservation System Benefits.

Benefit Assumptions	Value	Source
Miles Saved per Parking Space	15	FNTOP
Assumed Crash Reduction	15%	FNTOP
Hourly Value of Time (Truck Drivers)	$32.64	2021 UMR
Heavy Truck Fuel Economy (Miles Per Gallon)	6.60	BTS, 2019
Average Cost per Gallon of Fuel (Excluding Taxes)	$3.83	Avg. of April 5, 2022, and 2021
Value of Delay per Rural Crash	$4,679.83	Increased 2013 value to 2020 by 3% annually
Value of Delay per Urban Crash	$74,597.21	Increased 2013 value to 2020 by 3% annually

Table 2. Customized TOPS-BC Inputs for Truck Parking and Reservation System Costs (Priority 1 TxDOT, 2020b).

Cost Assumptions (per site)	N ≤ 20	N > 20
No. of Sites	26	8
No. of Parking Spaces	224	283
Peak Hr. Utilization	106%	130%
Detector/Sensor	per spot	entry/exit
Dynamic Message Signs	2	2
Network Equipment	1	1
Signage	1	1
Operational Support*	1	1
Preventative Operations & Maintenance (O&M)*	1	1
Software O&M and Licensing*	1	1

** Incremental deployment occurs once a year over 20 years.*

The research team used a 20-year horizon for the analysis. The two site groups (N ≤ 20 and N > 20) were combined to develop a single net present benefit of $40.1 million. The net present cost ranged from $9.7 to $14.4 million at 7 percent and 3 percent discount rates, respectively. In benefit-cost terms, the ratio varies from **2.8:1 to 4.1:1**.

Market Adoption

The deployment of TPAS can occur with conventional ITS, so it does not rely on the deployment of CVs. CVs may, however, offer alternative methods for detecting truck parking availability and communicating information to truck drivers, as well as TxDOT's ATMS and the DriveTexas™ website.

Connected trucks could help with detection in two ways: (a) reporting their occupancy of parking spaces and (b) reporting space occupancy observed while driving through a parking area. CVs could notify the TPAS when they occupy or depart a parking space, even at low CV adoption levels. In smaller parking areas with per-space detection, this would be a helpful check on sensor accuracy and a way to identify maintenance needs. CVs may also be capable of identifying open parking spaces as they drive through a parking area. Many newer models of passenger cars now come with automated parking assist systems, which can detect open spaces in parking lots and parallel parking areas (Song and Liao, 2016). If reported back to the TPAS, this information could supplement or replace other detection methods, especially as the adoption rate of CVs increases.

Increased adoption of CVs may also reduce the need for DMs to convey truck parking availability. CVs can receive real-time parking information through cellular or cellular vehicle-to-everything (C-V2X) networks and communicate this information to drivers through an ELD or navigation system. In addition, some passenger electric vehicles can now navigate to a charger reachable given the current battery level (*Model S Owner's Manual*, n.d.). With current technology, this implies that an analogous feature for trucks, navigating to an open parking space reachable given hours of service rules, is possible.

Level of Innovation

TPASs have already been deployed on a pilot basis in Texas and on a corridor level in other states like Florida (TTI, 2021; WTAD3x, n.d.). These systems rely on conventional ITS technologies, so the innovation is primarily organizational. For TxDOT, TxDPS, and third parties, a TPAS will collect a much richer dataset on truck parking than has been available to date. These data will help TxDOT and TxDPS plan investments in expanded parking areas and amenities at existing sites or open truck parking areas at opportunity sites. In addition, since the data will be publicly accessible, they may also be used by third parties to locate new private truck stops near public rest areas that are regularly over capacity.

A data feed for truck parking availability should be open to private truck stops that wish to supply data about parking availability at their facilities (MAASTO, 2019). The truck parking system deployed in eight midwestern states includes a few private truck stops, but integrating real-time parking availability from public and private facilities is still uncommon and can be considered a cutting-edge practice. Listing parking availability at a private truck stop should not be considered an endorsement but rather as providing information about an available service and enhancing safety, similar to the static Specific Service signs.

HIGH-RESOLUTION ADVANCED FREIGHT TRAVELER INFORMATION SYSTEMS

Practicality

As stated in the FNTOP, TMC-based ATIS is a well-developed concept and widely deployed, especially within more urbanized areas or highway corridors. ATIS generally serves the traveling public and is not usually tailored to the unique needs of freight movement. A specialized subset of ATIS is the Freight Advanced Traveler Information System (FRATIS), a bundle of applications that provides freight-specific dynamic travel planning and performance information. FRATIS optimizes drayage operations to coordinate load movements between freight facilities to reduce empty-load trips (USDOT, 2012). However, freight-specific traveler information systems have been limited in the scale of deployment and participation by freight-related and transportation firms due to the priority given to the general motoring public, managing roadways, limited resources, and the often unique informational needs of the freight community. Although ATIS systems provide information that trucking firms can use, the aftermarket often creates specialized applications leveraging such information to be even more helpful for trucking purposes.

Thus, TxDOT enhanced its existing ATIS systems to add capabilities specifically for freight movements such as freight information exchange, parking information, weather information, smart work zones, oversize/overheight/overweight vehicles, rail, and border crossings. This enhancement is a step toward providing "high-resolution" traveler information that the trucking industry can use to make more informed routing decisions, particularly in real-time and en route.

HRAFTIS intends to expand the capabilities of TxDOT's public-facing ATIS, DriveTexas™, to provide a high-quality freight traveler information service to the trucking industry on key truck routes in Texas. This strategy will enhance the granularity of traffic information on Texas roads by deploying TxDOT-owned sensor infrastructure and advanced third-party probe-based data on key limited-access and arterial truck routes. These data would be processed through advanced analytics tools—such as AI or Machine Learning—to identify incidents and forecast traffic conditions. TxDOT currently operates a traditional traveler information system and has been involved in exploring potential advanced analytics tools, but the complete implementation of the FNTOP strategy has not occurred yet.

This strategy leverages existing systems while aiming to expand both the coverage and granularity of traveler information available to motorists. TxDOT could make investments to advance and expand the current data collection, processing, and dissemination capabilities and invest in additional state-owned sensors and private sector probe data services to provide increased coverage of urban, suburban, and rural truck routes (as appropriate). In addition, TxDOT could collect and give the truckers dynamic traveler information such as truck parking availability (TPAS as discussed earlier) and static information such as height/weight road restrictions to provide high-quality freight data. Considering the multiple types and sources of information, implementing this strategy requires TxDOT to significantly invest in data processing tools and AI to convert raw field data into useful current and forecasted traveler information. Finally, TxDOT could consider establishing a trusted application programming interface (API) to broadcast data to the data users and distribute the data via other platforms, such as DriveTexas™ or other mobile applications widely used by the trucking industry.

Benefit/Cost Factors

The FNTOP included the following objectives of the HRAFTIS strategy:

- Expand TxDOT's DriveTexas™ to provide high-quality freight traveler information service.
- Enhance the granularity of traffic information on Texas roads.
- Build additional elements into the enhanced traveler information service that assist with freight routing decisions, such as freight weight limits for certain roadways or height restrictions.
- Provide an API-based architecture that securely allows TxDOT to collect and distribute data for public use.
- Create a mobile application (e.g., "DriveTexas™ Mobile for Freight") to provide real-time navigation routing tools.

Currently, TxDOT utilizes a network of ITS sensors and devices, primarily deployed in urban areas and private sector probe services, to collect data on highway conditions throughout Texas. TxDOT ATMS processes these data, publishes for the general public on DriveTexas^{TM}, and disseminates through regional TMCs and infield devices such as DMSs. Researchers assumed the utilization of private sector probe services in rural areas since it is more cost-effective than deploying detection, particularly considering O&M costs. In addition, researchers investigated how to provide more en-route traveler information opportunities in rural areas to complement this approach. Ideally, HRAFTIS would occur through the mobile "DriveTexas^{TM} Mobile for Freight," but this application could take a while to develop. More importantly, it may take time for sufficient market penetration of truck drivers to utilize the app (as there are multiple competing commercially available trucking apps). Thus, providing more DMSs, especially in rural areas, may bridge this gap to disseminate critical real-time traveler information to truck drivers who do not currently rely on mobile applications. Researchers compiled existing DMS locations and inventoried how many DMSs can be deployed to bridge this gap. Researchers identified strategic locations along the Primary Highway Freight Network based on two conditions: (a) between existing DMSs in urban areas and (b) where the Primary Highway Freight Network crosses the Texas Freight Network. Ninety DMSs are needed to achieve this approach, as listed by corridor in Table 3. However, given that the mobile app development should occur before the 20-year horizon period and the significant cost to deploy all 90 DMSs, researchers reduced the number of DMSs to more realistic targets and analyzed three deployment levels: 23 (25 percent), 30 (33 percent), and 45 (50 percent) for planning purposes.

Table 3. Proposed Rural Dynamic Message Signs by Corridor.

Highway	From	To	DMS
IH10	El Paso	San Antonio	12
IH10	San Antonio	Houston	7
IH20	IH10	Weatherford	15
IH44	Burkburnett	(both directions)	2
IH40	W. of Amarillo	(both directions)	2
IH27	Amarillo	Lubbock	6
IH30	Rockwall	Mt Pleasant	4
IH20	Balch Springs	Marshall	3
IH45	Hutchins	Conroe	5
IH35	San Antonio	Laredo	12
IH37	San Antonio	Corpus	12
US77	Kingsville	(both directions)	2
US57	Eagle	IH35	8
			Total 90

The research team developed BC ratios for three DMS deployment target levels using available data from various sources and FHWA's TOPS-BC tool (Sallman et al., 2012). Table 4 and Table 5 show the customized TOPS-BC inputs for HRAFTIS benefits and costs, respectively.

Table 4. Customized TOPS-BC Inputs for HRAFTIS Benefits.

Benefit Assumptions	Value	Source
Average Daily Traffic (ADT) Passing by DMS	47,000	Average 2020 ADT—All Vehicles (TxDOT RHiNo)
User Entered Benefit (Annual $' s)	$3.69 million	TxDOT Portion (by miles) of Safety, Environmental, and Vehicle Costs from I-10 ATCMTD TPAS Grant

Table 5. Customized TOPS-BC Inputs for HRAFTIS Costs.

Cost Assumptions	Qty.	Cost
No. of Infrastructure Deployment[1]	1	$527,130
No. of Incremental Deployments[2]	23, 30, 45	$423,292–$828,180

1. TMC Hardware/Software, ATMS integration, and Archived Data Mgmt. Systems.
2. Communication Line, DMS, and DMS Structure.

Using a 20-year horizon, the calculated net present benefit was $64,971,290, and the net present cost ranged from $7.1 million to $17.0 million at discount rates of 7 percent and 3 percent, respectively. In benefit-cost terms, the ratio varies from **3.6:1 to 8.3:1,** as shown in Table 6 and Table 7.

Table 6. HRAFTIS BC Ratios, Discount Rate of 3%.

Qty.	Costs	BC ratio
23	$9,546,575	6.8:1
30	$12,293,191	5.3:1
45	$18,178,797	3.6:1

Table 7. HRAFTIS BC Ratios, Discount Rate of 7%.

Qty.	Costs	BC ratio
23	$7,785,795	8.3:1
30	$10,036,007	6.5:1
45	$14,857,890	4.4:1

Market Adoption

Deployment of a HRAFTIS can occur with conventional ITS, but the increased deployment of CVs could provide a source of granular data and a method for disseminating customized traveler information.

Researchers assumed that a HRAFTIS would rely on probe data for areas outside current ITS sensor coverage. Some probe data sources do not separate passenger vehicles and trucks in their speed and volume estimates, while those that do sometimes suffer from small sample sizes and missing data (Karimpour et al., 2019). For a HRAFTIS to be accurate and relevant to trucks, probe data separated by vehicle class and other characteristics (e.g., oversize/overweight loads) would be highly desirable. CVs can report both traffic conditions (i.e., speed, travel time, roadway conditions) and vehicle attributes (i.e., classification, size, weight).

CVs could also establish two-way communication with a HRAFTIS and receive travel information customized to their vehicle characteristics that are not practical to distribute via DMSs or public websites. For example, trucks often have a lower average speed than passenger cars, and the difference can widen significantly in mountainous terrain. The HRAFTIS could provide travel time to CVs based on vehicles in the same or similar class. Similarly, in a major incident, passenger cars may be able to use a parallel route that is not suitable for trucks due to low clearance or weight limits. The HRAFTIS could provide alternate route information suitable for the height and weight of a CV.

Level of Innovation

The HRAFTIS strategy is innovative on a technical level in two ways: by enabling two-way communication with roadway users and by automating the dissemination of particular messages.

Current traveler information systems push information about traffic conditions, incidents, construction, and weather conditions out to roadway users. Still, these systems are generally one-way communications channels (e.g., DMSs, highway advisory radio, DriveTexas™) that do not receive any information from users. A HRAFTIS could establish two-way communication with CVs and receive information from vehicle sensors, such as locations of damaged or unreadable signs. This type of information could improve the efficiency of TxDOT's maintenance practices.

Current TxDOT practice relies on TMC operators to write and publish messages on DMSs. Messages for CVs, however, are standardized for machine readability and could be generated automatically by scripts processing real-time data. Automating these messages would avoid adding to the TMC operator workload.

BINATIONAL TRAFFIC OPERATION CENTER

Practicality

From a technological standpoint, a binational TOC relies on proven technology already implemented elsewhere in Texas and other states and countries. The FNTOP Strategies and Conceptual Framework (Freight Planning Branch, 2020) suggested three possible levels of implementation:

- **Low:** Consists of an archived data management system accessible to all participating agencies. The system does not support real-time data feeds and primarily would be used for analysis and planning purposes. Virginia Department of Transportation (DOT) has implemented a similar data management system in its regional traffic incident management information systems (RTIMIS) program.
- **Medium:** Consists of data sharing plus real-time communications between participating agencies. A similar system has been implemented by the Metropolitan Area Transportation Operations Coordination (MATOC) program in the Washington, DC area,

including Virginia DOT, Maryland DOT, and the Washington Metropolitan Area Transit Authority.
- **High:** Consists of data sharing and real-time communications plus a physical location staffed by U.S. and Mexican agency representatives. The international element adds some complexity, but examples of multiagency TOCs exist, such as the Combined Transportation, Emergency, and Communications Center (CTECC) built by Austin and Travis County.

A study conducted in 2016 identified two potential issues for implementation: regulatory uncertainty and ITS deployment (Macias et al., 2016). Regulatory uncertainty exists at both the state and federal levels. At the state level, TxDOT does not have the statutory authority to sign an agreement with an agency in Mexico. FHWA does not explicitly allow for data from federally funded ITS devices to be shared with agencies outside the United States at the national level. A similar state of uncertainty exists on the Mexican side, given multiple agencies with border crossing responsibility and no clear legal guidance on data sharing with foreign agencies. Implementation would require either legislative/regulatory action to explicitly allow data sharing or a workaround like sharing data via a third party, which appears to be possible (Macias et al., 2016).

The implementation levels described in the FNTOP focus on data sharing and communications platforms. However, the existing state of ITS deployment may not be sufficient to support desired TOC functions and would likely require additional field assets. Technology reviews in several recent reports show significant data gaps (Rajbhandari et al., 2012; Macias et al., 2016; Freight Planning Branch, 2020; TxDOT, 2021).

TMCs currently exist in the TxDOT El Paso and Laredo districts and the city of McAllen. There is presently no TMC for the Pharr District or any of the border cities in Mexico. A report from 2012 mentioned plans by the Secretaría de Comunicaciones y Transportes (SCT) in Mexico to build TMCs in Chihuahua and Monterrey that would monitor federal highways and toll roads leading to the U.S. border (Rajbhandari et al., 2012). It is unclear whether these plans have advanced since 2012, but in any case, not all border crossings connect to Mexican federal highways.

All border districts have DMS, permanent count, and weigh-in-motion coverage in terms of ITS assets. The El Paso region is well-instrumented with closed-circuit television (CCTV) cameras and detectors (Freight Planning Branch, 2020). The Laredo District maintains CCTV cameras in Del Rio and Laredo and a limited number of detectors in Laredo. The Pharr District has no CCTV cameras or detectors. TTI's Border Crossing Information System (BCIS) monitors wait times and crossing times in the northbound direction only on seven commercial crossings (*Border Crossing Information System—Real-Time Information*, n.d.). Notable data gaps include southbound crossing volumes, wait times, crossing times, and speed and volumes for major roads on the Mexican side (TxDOT, 2021). The instrumentation on the Mexican side would need to be purchased and maintained by Mexican agencies. Yet, there are essentially no funding sources or mechanisms for ITS infrastructure at any level of government (Macias et al., 2016).

Benefit/Cost Factors

Potential benefits of a binational TOC include:

- The ability to provide real-time wait times and crossing times to users. Better traveler information will lead to better traffic distribution between border crossings, reducing travel delays and queue spillback issues.
- Data standardization leads to better systematic monitoring and evaluation of the border transportation system. In addition, established standards will help agencies on both sides of the border make better operational (i.e., staffing levels, toll rates) and planning (i.e., capacity expansions, new crossings) decisions.
- Better inter-agency communication. Border crossings are a multi-step process, and a typical northbound commercial crossing includes Mexican customs, toll collection, U.S. customs, and TxDPS inspection. Therefore, the crossing will operate most efficiently if all agencies coordinate their staffing levels to provide a similar capacity level.

Analysts can estimate the first of these accrued benefits with the En-Route Traveler Information template in FHWA's TOPS-BC tool (Sallman et al., 2012). The second and third benefits mainly accrue to public agencies and are difficult to quantify.

Costs of a binational TOC (with FNTOP implementation level in parentheses) include:

- Developing an archived data management system (low).
- Maintaining an archived data management system (low).
- Connecting ITS data feeds for real-time monitoring (medium).
- Supporting inter-agency communications (medium).
- Computer hardware and networking equipment for physical TOC (high).
- Operations and maintenance for physical plant (high).
- Staffing physical TOC (high).
- Installing additional ITS field equipment (not covered in FNTOP).

The FNTOP estimated capital, operations, and maintenance costs are shown in Table 8. Macias et al. (2016) also estimated the cost of a cross-border TMC. The costs and scope shown in Table 9 are similar to the high deployment case in the FNTOP.

Table 8. FNTOP Cost Estimates.

Deployment	Capital Cost	Annual O&M Cost
"Low" Deployment (Cross-Border Data Sharing)	$394,538	$526,051
"Medium" Deployment (Virtual TOC, Data Sharing)	$394,538	$2,138,751
"High" Deployment (Physical TOC, Data Sharing)	$8,386,665	$5,527,798

Source: (Freight Planning Branch, 2020).

Table 9. Cost Estimate for Basic TMC in the United States.

	Basic TMC	Unit Cost	Qty	Subtotal
Basic Functions				
	Advanced Traffic Management System Software	500,000	1	$500,000
	Supporting Software	350,000	1	$350,000
	Video Wall/Displays	250,000	1	$250,000
	Workstations	20,000	4	$80,000
	Furniture	25,000	4	$100,000
	Backup Power/Filters	250,000	1	$250,000
	Servers/Racks/Support	200,000	1	$200,000
	Internal Comm	250,000	1	$250,000
	External Interfaces	100,000	1	$100,000
	Binational Comm/Connections	200,000	1	$200,000
	Power/Building Improvements	400,000	1	$400,000
	Subtotal			*$2,680,000*
	Management/Procurement		0.15	$402,000
	Design/Engineering		0.2	$536,000
	Revised			$3,618,000
	Contingency		0.2	$723,600
	Subtotal			**$4,341,600**
Basic Field Devices (including basic enclosures/mounting)				
	Dynamic Message Signs (Medium)—Comm Wireless/AC Power	175,000	8	$1,400,000
	Border Wait Time Detection—Comm Wireless/AC Power	12,000	32	$384,000
	Border Wait Time Detection—Comm Wireless/Solar Power	20,000	8	$160,000
	Travel Time Detection—Comm Wireless/AC Power	25,000	12	$300,000
	Basic Queue Cameras (Wireless/AC)-Fixed—Existing Structure	15,000	8	$120,000
	Traffic Surveillance Cameras (Wireless/AC)—PTC w/Pole	40,000	8	$320,000
	Subtotal			*$2,684,000*

	Management/Procurement		0.15	$402,600
	Design/Engineering		0.15	$402,600
	Revised		0.15	$402,600
	Revised Subtotal			$3,489,200
	Contingency		0.2	$697,840
	Subtotal			**$4,187,040**
	Total Estimate			**$8,528,640**

Source: (Macias et al., 2016).

Benefit/Cost Calculation

Based on the information found in the literature review, the research team performed a high-level benefit/cost calculation. The benefit side includes only en-route traveler information since the other two benefits are primarily internal to public agencies and were not easily quantified. The research team estimated the benefits of en-route traveler information for seven currently instrumented CMV crossings as part of BCIS using FHWA's TOPS-BC tool. Table 10 presents the inputs and range of values for the tool. The research team assumed the binational TOC would disseminate border crossing times continuously and not just when long delays or incidents were affecting the crossings. The research team tested a range of driver parameter values for sensitivity testing. Two important factors will influence these parameters: the presence of an alternate crossing and the willingness of drivers to reroute.

Table 10. TOPS-BC Inputs for En-Route Traveler Information.

Input	Range	Source
Volume Passing Sign Locations	12,677	Average AADT of seven CMV crossings currently in BCIS
Percent Time Device Disseminates Useful Information	84%	Hours per day that seven CMV crossings are currently open
Percent Drivers Acting on the Information	10–20%	Estimated
Average Time Saved (Minutes) by Drivers Acting on the Information	4–20	Estimated
Average Time Saved (Minutes) by Drivers Not Acting on the Information	0–5	Estimated
Number of Periods Per Year	365	Days seven CMV crossings are open

Of the seven crossings currently instrumented for BCIS, three are relatively isolated, meaning drivers are unlikely to reroute unless an incident closes the crossing. These three crossings entail the Veteran's Memorial Bridge in Brownsville, Pharr-Reynosa Bridge, and Camino Real International Bridge in Eagle Pass. The four remaining crossings can be divided into two possible substitutes for each other: Bridge of the Americas and Ysleta-Zaragoza in El Paso, and Colombia and World Trade Bridge in Laredo. However, neither is a perfect substitute. In El Paso, many trucking companies and drivers prefer the Bridge of the Americas since it is centrally located and has no toll. In Laredo, the warehouses on the U.S. side are clustered around the World Trade Bridge, meaning that the Colombia Bridge is a significant detour for drayage drivers, who represent the majority of drivers crossing the border.

The cost side uses the FNTOP's figures for the medium deployment of a virtual TOC and data-sharing platform. The research team chose this scenario because the low deployment does not support real-time applications. A virtual TOC offers most of the benefits of a physical TOC (the high deployment scenario). Furthermore, a virtual TOC could convert to a physical TOC in the future. The FNTOP's review suggests that the difference between a virtual and physical TOC is primarily the capital cost of building out a physical space. As shown in Table 8, the medium deployment costs include an up-front capital cost of $394,538 and an annual operation and maintenance cost of $2,138,751.

For benefit/cost estimation, the research team used a 20-year horizon and two different discount rates, 3 percent and 7 percent. The benefit calculations in the TOPS-BC tool proved to be quite sensitive to the values selected for the driver parameters, with annual benefits ranging from $511,762 to $10,235,246, depending on the exact values selected from the ranges provided in Table 10. Net present value over the 20-year horizon ranged from $17,630,883 to $120,060,870, depending on the selected parameter values and discount rate. In benefit-cost terms, the ratio varies from **0.2:1** to **4.7:1**.

Market Adoption

The binational TOC strategy is not particularly dependent on the adoption of CVs. For example, implementing a data-sharing platform, virtual TOC, or physical TOC could occur with current low CV penetration rates. Increased CV adoption does, however, present opportunities to collect data and disseminate traveler information in different ways.

On the data collection side, the following technologies are used (Macias et al., 2016):

- License plate readers (CBP).
- RFID tags (CBP, toll collection systems, BCIS).
- CCTV cameras (Mexican customs, TxDOT).
- Loop and radar detectors (TxDOT).

CVs could supplement or replace these data collection methods. For example, at ports of entry, the Architecture Reference for Cooperative and Intelligent Transportation (USDOT, 2021) includes an application for border management systems, which CBP and Mexican customs could use to retrieve vehicle information, traveler information, and cargo manifests. CVs can also be a source of probe data to monitor wait times, crossing times, and traffic conditions on major routes. These data would be valuable for southbound commercial crossings and significant routes in Mexico not instrumented today.

On the information dissemination side, the publication of BCIS data on a public website occurs in real-time but does not integrate into Lonestar^{TM}. On the U.S.-Canada border, DMSs are used to share crossing times with the public, a practice that TxDOT could adopt if southbound crossing times become available. Still, many drivers do not check the BCIS website, and DMSs do not cover all routes. CVs offer a method of broader dissemination and could reroute drivers to a shorter crossing through in-vehicle navigation.

Level of Innovation

The binational TOC strategy is mainly innovative from an organizational standpoint. Currently, no binational TOCs exist elsewhere on the U.S.-Mexico border or the U.S.-Canada border (Macias et al., 2016). The closest parallels are a planned TMC connection in California, data sharing agreements on the U.S.-Canada border, and data sharing standards in the European Union.

In California, plans for a new Otay Mesa East border crossing include building a TMC in Tijuana that would monitor crossing times at all Tijuana-San Diego area crossings (Macias et al., 2016). The proposed Tijuana TMC would connect to the San Diego TMC, and crossing time information could help set variable tolls at Otay Mesa East. However, the project is still in the planning stages, and construction has not started.

The United States and Canada established a Border Information Flow Architecture in 2001, which sets data standards and ensures technology interoperability (Macias et al., 2016). An ATIS between British Columbia and Washington State ATIS started in 2004 and communicates information about border wait times via DMSs and other channels. Cross-border TMC connections have been included in ITS architectures in Vermont, Buffalo-Niagara, and New Mexico but have not been implemented yet.

The DATEX2 standard governs the exchange and formats for traffic data in the European Union (*Homepage | DATEX II*, n.d.). This standard supports data sharing between TMCs, news broadcasters, incident response teams, and firefighters within and between national borders. The Project for the Management of European Traffic (PROMET) established a TMC connection between Italy, Slovenia, and Austria starting in 2007. The context of PROMET is somewhat different from U.S. border crossings since all three countries are in the Schengen Area and have no passport or customs checks at the border.

CHAPTER 4 IMPLEMENTATION FRAMEWORK FOR NEXT STEPS

This chapter develops an implementation framework for the institutionalization of the TCFC system into a broader program. The framework provides context concerning considerations for procurement, deployment, research gaps, and funding/grant opportunities relative to the two selected applications: Truck Parking Availability System and High-Resolution Advanced Freight Traveler Information System.

TRUCK PARKING AVAILABILITY SYSTEM

Procurement

Implementation of the TPAS consists of three main components: development of a data feed, deployment at primary sites, and development of secondary sites. These components would be best deployed in the order listed, although concurrent deployment is also possible.

Develop Data Feed

The first important component of a statewide TPAS is the data feed that would collect real-time availability at all instrumented truck parking areas and distribute this information via a public website and/or API. As described in previous chapters, recent technological developments suggest that this data feed could become the primary distribution channel for truck parking information, although roadside DMSs may still be necessary to serve truck drivers who do not monitor websites or apps.

Contributors. An open question is who would be allowed to contribute truck parking data to the feed. Possibilities include:

- Closed system, which includes data from TxDOT facilities only.
- Trusted user system, which includes data from multiple sources (e.g. TxDPS, private truck stops) approved by TxDOT.
- Crowdsourced system, which could include data from both facility owners (i.e., TxDOT, TxDPS, private truck stops) and user contributions.

A closed system would give TxDOT complete control over data accuracy. A trusted user system would still be managed by TxDOT, who could impose minimum standards for data accuracy, update frequency, and so on. A crowdsourced system would be difficult to validate but could provide much greater coverage than sensors. As noted in earlier chapters, closed and trusted user systems currently exist in other states.

Specification. The data feed should follow a standard format so that it can be used by websites, mobile apps, ELDs, and other end users. One option would be to use the specification described in the *Regional Truck Parking Information Management System (TPIMS) Data*

Exchange Specification Document, which appears to have all the necessary fields and would have the added benefit of ensuring interoperability between TxDOT's system and the existing Mid America Association of State Transportation Officials (MAASTO) truck parking information management system (TPIMS) project which includes eight states (MAASTO, 2019).

MAASTO's specification includes two feeds: a dynamic feed which contains real-time availability and is updated every 1–5 minutes, and a static feed which contains metadata for all truck parking sites and is only updated as needed. Both feeds are provided in JavaScript Object Notation (JSON) format. The field descriptions for the dynamic feed are shown in Table 11, and the field descriptions for the static feed are shown in Table 12.

Table 11. Dynamic Feed Specification from MAASTO.

Element	Type	Description
siteId	string	Unique fixed-length identifier including state, route number, route type, reference post, side of road, and unique location number or name abbreviation. See more detailed description in appendix.
timeStamp	string	Provides the date and time that the site record was last updated. See more detailed data and time representation description in appendix.
timeStampStatic	String	Provides the date and time that the site static record was last updated. See more detailed data and time representation description in appendix.
reportedAvailable	string	Number of available spots shared through the data feed. The number is capped at the total number of parking spots at the site, and "Low" is reported if the low threshold is reached.
trend	string	Optional. Reports whether the site is emptying, steady, or filling. Accepted values: **"CLEARING"/"STEADY"/"FILLING"/null**. See more detailed description in appendix.
open	boolean	Will report open unless the parking site is closed to parking for maintenance or another situation. Possible values: **true/false/null**.
trustData	boolean	This flag will report that the site is operating normally. Possible reasons for a "false" value include periods where the site is under construction while open to traffic, IT maintenance windows, or equipment failures. Possible values: **true/false/null**.
capacity	Number	Total number of parking spots within the site.

Source: MAASTO, 2019

Table 12. Static Feed Specification from MAASTO.

Element	Type	Description
siteId	string	Unique fixed-length identifier including state, route number, route type, reference post, side of road, and unique location number or name abbreviation. See more detailed description in appendix.
timeStamp	string	Provides the date and time that the site record was last updated. See more detailed data and time representation description in appendix.
relevantHighway	string	Provides the highway from which the truck parking area can be accessed. The highway number, followed by "IS" for interstate, "US" for US highway, or "SH" for state highway. There is no space between the number and roadway type indicator.
referencePost	string	Provides the Reference Post (mile marker) for the center of the rest area or interchange.
exitID	string	At interchanges, the designated interchange number is provided. For rest areas and weigh stations that do not have an exit identification the value will be set to null.
directionOfTravel	string	Text indicating the direction(s) of travel that can access the site (Eastbound—E, Westbound—W, Northbound—N and Southbound—S). For sites that can be accessed by either direction of travel, a bidirectional identifier such as "NS" or "EW" can be used.
name	string	Name of facility as text (e.g., Rest Area or Flying J Truck Stop).
location	array	This array contains the seven following data elements about the site's physical location:
latitude	number	The latitude in a float format.
longitude	number	The longitude in a float format.
streetAdr	string	Text based address number and street name.
city	string	Name of city in which the parking area is located. If not in a city, the county name can be used (e.g., Johnson County).
state	string	Abbreviation for state in which the parking area is located.
zip	string	ZIP code of the location
timeZone	string	Time zone
ownership	string	Text used to indicate whether a parking site is privately owned or publicly owned. Accepted values: **"PR"/"PU"**
capacity	number	Total number of parking spots within the site.
amenities	Array of strings	Optional. List of text based amenities descriptions. Data structure would allow a varying number of amenities to be listed.

images	Array of strings	Optional. Provides a link to an image file on a server that shows the lot status visually. This is only used if images are being captured and shared from a surveillance camera, otherwise it will be null.
logos	Array of strings	Optional. Provides a link to an image file on a server that shows the private truck stop logo or TPIMS logo.

Source: MAASTO, 2019

Hosting. The research team recommends that the truck parking availability system be hosted in the same location as DriveTexas^{TM}.

Deploy TPAS at Primary Sites

The second component to deploy a TPAS is to instrument existing truck parking areas. As described in Chapter 3, the TxDOT Texas Statewide Truck Parking Study identified 34 primary sites, which include existing rest areas, traveler information centers, and parking areas (TxDOT, 2020). Based on a review of current detection technologies, the research team proposed to divide these sites into two groups: small sites (i.e., 20 or fewer parking spaces) and large sites (i.e., more than 20 spaces).

Small Sites. For small sites, the research team recommends per-space detection. This approach has been evaluated in the pilot project at the Walker County SRA on IH-45 (TTI, 2021). With this detection method, sensors are installed in each marked truck parking space. Multiple sensors are used to avoid false positives and to provide a backup in case one sensor fails. The IH-45 site uses three multiple-technology (i.e., infrared and magnetic) in-ground sensors per space, centered in the lanes and separated longitudinally by 33 ft. TTI discovered early in monitoring the sites that the longitudinal spacing should have been less than 33 ft due at least in part to the prevalence of short vehicles such as trucks pulling intermodal chassis and tractors without trailers. Using three sensors per space is adequate, but spacing should be reduced from 33 ft to 15–20 ft.

Large Sites. For large sites, the research team recommends entry-exit detection. This approach was also evaluated in the pilot project at the Walker County SRA on IH-45 (TTI, 2021). With this method, sensors are installed at the entrance and the exit of the truck parking area. Non-intrusive detection has benefits such as not requiring closure of entry and exit points during installation and maintenance. Given that a pole was needed at the entry and exit points for mounting solar panels, equipment cabinets, and a camera, it seemed reasonable to install sensors that could be pole-mounted on the same pole. Due to the expectation that entering and exiting trucks might stop underneath the sensor, TTI installed sensors that had exhibited the capability of accurately counting queueing vehicles (LeddarTech IS16). While monitoring trucks entering and exiting, TTI found instances where trucks parked for several hours underneath the sensor; this required a mast arm for moving the sensor further from the pole itself and closer to the desired detection point.

Develop Secondary Sites for Truck Parking

The third component is to develop secondary sites to increase truck parking capacity in strategic locations. Secondary sites identified in the TxDOT Texas Statewide Truck Parking Study included 42 sites, such as closed rest areas, surplus TxDOT properties, and TxDPS weigh stations, that could be expanded to include parking areas (TxDOT, 2020).

Because secondary sites are not currently open for truck parking, they would require some construction in addition to sensor installation. Depending on the site, construction work may include site preparation, paving, striping, and amenity installation. The TxDOT Texas Statewide Truck Parking Study named lighting, trash cans, and toilets as the basic amenities expected for a truck parking facility (TxDOT, 2020). The research team assumed that sensors for secondary sites would follow the same process as primary sites.

Research Gaps

There has been significant interest in and research about truck parking in recent years. Still, additional work on detection methods and route planning could be beneficial to the design and use of a TPAS in Texas.

Detection Methods

As described in Chapter 2, the literature review conducted by the research team found three main detection methods:

- Per-space: a sensor is installed in each parking space.
- Entry/exit: sensors are installed at the entrance and exit of the truck parking area.
- Overhead: a camera is installed high on a pole, providing an overview of the truck parking area, and image recognition is used to determine which spaces are occupied.

Based on the literature and TTI's experience with a pilot project, per-space detection is generally reliable but has a large number of sensors to install and maintain and is only able to detect trucks parked where sensors are installed. Entry/exit detection is inexpensive to install, but errors can accumulate over time, so periodic manual counts and resets may be required. A main source of errors are automobiles entering the truck parking area in error and exiting through the truck parking entrance, creating a discrepancy between the entry and exit counts. Overhead detection is also inexpensive to install, but visual detection may be less reliable at night or in inclement weather. Additional research comparing the lifecycle cost or accuracy of different detection methods would be highly valuable. For example, overhead detection may be inexpensive to install but may be more expensive to maintain due to required equipment and labor. Another desirable research topic could be techniques for validation and error correction, particularly for entry/exit detection where cumulative errors are known to be an issue.

Route Planning

TPAS are in an early stage of deployment nationwide. Current technology generally requires truck drivers to manually consult and process availability information, whether through a roadside DMS, website, or mobile app. There is significant potential for researchers or the private sector to develop driver assistance features as more truck parking data becomes available. One idea, as noted in Chapter 3, is for truck navigation systems to take hours-of-service rules into account and suggest parking locations that the driver can reach based on current traffic conditions and parking availability. However, since many parking locations fill up in the overnight hours, another useful research topic could be forecasting parking availability at time of arrival.

Electrified Parking Spaces for Trucks

As part of the TPAS and the expansion of truck parking at secondary sites, the implementation of electrified parking spaces (EPS) for trucks could be investigated. This implementation would include a per space availability monitoring system as suggested for smaller parking areas. EPS/truck stop electrifications (TSE) have been deployed in many locations, and there is a mature and standardized technology base for implementation. The implementation of EPS for truck parking would fit well with other statewide freight operation projects and the statewide electrification and charging program.

Driver comfort is essential to the job of long-haul trucking, and sometimes truck drivers must run their engines to stay warm or cool in their trucks while resting. But long-duration idling is also costly to the driver, to the fleet owner, and to the environment.

Benefits from reducing long-duration idling include:

- Decreasing fuel costs.
- Decreasing engine maintenance costs.
- Extending engine life.
- Improving operator well-being by decreasing noise levels.
- Decreasing emissions that are harmful to the environment.

Included in the U.S. Environmental Protection Agency approved Idling Reduction Technologies for long haul, Class 8 trucks equipped with sleeper cabs are EPS/TSE for trucks. Electrification refers to a technology that uses electricity-powered components to provide the operator with climate control and auxiliary power without having to idle the main engine. This includes electrified parking spaces or systems that directly provide heating, cooling, or other needs. An

EPS system operates independently of the truck's engine and allows the truck engine to be turned off as the EPS system supplies heating, cooling, and electrical power (*Learn About Idling Reduction Strategies | U.S. Environmental Protection Agency*, n.d.).

The EPS system provides off-board electrical power to operate the following:

- Independent heating, cooling, and electrical power system.
- Truck-integrated heating and cooling system.
- Plug-in refrigeration system that would otherwise be powered by an engine.

Grant Possibilities

FHWA issued a memorandum in 2018 to clarify the funding eligibility of truck parking projects. This guidance is not expected to change significantly as funding from the Infrastructure Investment and Jobs Act (IIJA) becomes available, but new grant programs could be introduced.

Nationally Significant Multimodal Freight and Highway Projects (INFRA)

The INFRA grant program was renewed in the IIJA and will have a total of $7.25 billion available for fiscal year (FY) 22–FY26 (*The INFRA Grants Program | U.S. Department of Transportation*, n.d.). Truck parking projects are eligible as a project that improves safety and/or improves critical freight movements. The location criteria for freight projects are that they are either on the National Highway Freight Network or within the boundaries of an intermodal facility e.g., rail facility or port).

Rebuilding American Infrastructure with Sustainability and Equity (RAISE)

The Better Utilizing Investments to Leverage Development (BUILD) grant program was renamed RAISE in the IIJA (*RAISE Discretionary Grants | U.S. Department of Transportation*, n.d.). A sum of $1.5 billion in funding was available in the FY22 cycle, which closed in April 2022. RAISE is a broad program for funding capital improvements to infrastructure. In the 2022 round of funding, "mobility for freight and supply chain efficiency" was named as a specific emphasis area.

Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT)

The estimated total PROTECT funding is $7.3 billion for FY22–26. The purpose of this programs is to provide funds for resilience improvements through formula funding distributed to states. The goal of the competitive planning grants is to enable communities to assess vulnerabilities to current and future weather events, natural disasters, and changing conditions, including sea level rise, and plan transportation improvements and emergency response strategies to address those vulnerabilities. The competitive resilience improvement grants aim to protect surface transportation assets, communities, coastal infrastructure, and natural infrastructure through resilience improvements and strategies.

HIGH-RESOLUTION ADVANCED FREIGHT TRAVELER INFORMATION SYSTEM

Procurement

HRAFTIS can be implemented in three main phases, which are outlined in the subsections below.

Expand Capabilities of DriveTexas™

The research team recommends that implementation of the HRAFTIS strategy begin with the introduction of a freight traveler information service within DriveTexas™. This could be done by writing additional software using the existing website and server. The advantage of beginning with this step is that the HRAFTIS would be launched early in implementation, providing a basic service that would be expanded with additional features and data sources as implementation continues.

The initial freight traveler information service would focus on providing freight-specific information, such as travel times, weather information, work zone locations, incident information, and truck parking availability (if the previous strategy is implemented concurrently). Data for the initial phase would come from TxDOT-owned ITS assets, third-party probe data, and CV data collected by the TCFC roadside units (RSUs).

Deploy Additional ITS Assets

The second implementation phase would significantly expand ITS coverage along the Primary Highway Freight Network. As described in Chapter 3, TxDOT's current ITS coverage is mostly limited to urban areas. The research team proposed deploying DMSs at strategic locations in rural areas. DMS deployment is a near-term strategy to reach truck drivers who may not check DriveTexas™ or have any CV features. These signs could be used to provide travel times in normal conditions and alternate route information in case of inclement weather, construction delays, or incidents. DMS procurement could follow the same specifications as recent deployments, with backhaul communications using either fiber optic or 4G/5G cellular based on-site conditions. The research team recommends including a RSU with each DMS, since this would expand RSU coverage beyond the initial TCFC deployment and bring in additional CV data.

Develop New Dissemination Tools

The third phase of HRAFTIS deployment is to develop new dissemination tools, both to provide new types of information to freight users and to reduce the reliance on physical ITS infrastructure.

The first step is to develop additional dissemination methods. Chapter 3 discussed three methods: an API, a TxDOT mobile app, and two-way communications with CVs. The API would be an extension of DriveTexas^{TM} and could be housed on the same server. It would provide the same real-time data as DriveTexas^{TM} in a machine-readable format for integration into third-party mobile apps, ELDs, and/or vehicle navigation systems. The TxDOT mobile app would be an alternative to the DriveTexas^{TM} website. It should, at a minimum, support both iOS and Android and provide the same information as the website. A more advanced mobile app would provide customized traveler information, as described below. Finally, CV communications would allow the HRAFTIS to receive data from CVs and provide customized traveler information through RSUs.

The second aspect of this phase is providing additional freight-specific information. Existing ATIS systems provide one-way communication from TxDOT to the traveling public, and the information is not customized by vehicle class. Customized traveler information could be provided if users input certain information, such as their destination, vehicle class, gross vehicle weight, height, width, etc. To provide this type of customized freight traveler information, the HRAFTIS would need access to data such as truck-lane restrictions, relative and verified attributes from TxDOT's Roadway-Highway Inventory Network Offload database (RHiNo), bridge clearances, and active work zones.

Research Gaps

There has been significant research on CVs, traveler information systems, and probe data in recent years. However, most of the existing research has focused on passenger vehicles. There has been some work on freight, but more research in this area could be valuable to TxDOT in implementing a HRAFTIS.

Truck-Specific Forecasting and Routing

Pre-trip route planning for trucks is generally a mature topic. Such tools are commercially available, and automated route generation is possible even for most oversize/overweight loads applying for single-trip permits in the Texas Permitting and Routing Optimization System. However, a HRAFTIS would be asked to provide real-time routing for trucks, which includes short-term forecasting of travel times. Recent research has shown that link-based travel time forecasts mask considerable variation between vehicle trajectories (Hale et al., 2021). This finding is likely to be particularly important for trucks, which have slower acceleration and braking performance and greater difficulty in changing lanes compared to passenger vehicles. Further research could be valuable to understand truck travel times on congested roadways and to produce route recommendations that respond to industry preferences (i.e. the relative importance of shortest mileage, shortest travel time, travel time reliability, fuel consumption, and other factors).

Truck Probe Data

As noted in Chapter 3, not all probe data sources currently separate passenger vehicles and trucks in their speed and volume estimates. Even for sources that do, data for trucks may be sparse in some areas due to low volumes, low penetration rates, or both. Research could help fill gaps in probe data by developing imputation methods that estimate truck speeds and travel times from some combination of historical truck data and real-time passenger vehicle data. Research on this topic would be most useful in the short term, since probe data and CV penetration rates are likely to increase over time, alleviating some of the gaps in coverage.

Grant Possibilities

Strengthening Mobility and Revolutionizing Transportation (SMART)

This grant program was established by the IIJA and includes $1 billion in funding. A HRAFTIS response to multiple emphasis areas described eligible uses as: connected vehicles, intelligent sensor-based infrastructure, systems integration, and commerce delivery and logistics (*Strengthening Mobility and Revolutionizing Transportation (SMART) Grant Program*, n.d.).

Rural Surface Transportation Grant Program

This grant program was established by the IIJA and received $2 billion in funding. Since many of the investments proposed to implement a HRAFTIS are in rural areas, it may be a good target for this grant program, whose areas of emphasis include "improving safety and reliability of the movement of people and freight" (USDOT, 2022).

CHAPTER 5 CONCLUSION AND FINDINGS

For this project, the research team reviewed and assessed a set of technologies and strategies to expand the number of applications for the TCFC project. As of the date of this report, the TCFC project plans to implement at least five specific applications for inclusion within the CV environment. The applications include queue warning, work zone warning, wrong-way driving, ATIS, and freight signal priority.

The research team investigated the suitability of additional applications through a three-step process, first by focusing on a review of existing literature and outreach to private sector trucking firms. Then, the team estimated the cost and benefits of implementing a select list of CV applications through a quantitative approach. Finally, the team recommended an implementation pathway by identifying existing procurement standards and potential future grant possibilities.

The literature review began with an initial assessment of the 12 technologies identified from the TxDOT FNTOP. Next, the review summarized findings related to similar national deployments, recent activities, and the outcomes of selected projects (i.e., successes and setbacks). Overall, the research team identified three potential applications for further analysis, which consisted of (a) TPAS, (b) HRAFTIS, and (c) the Binational TOC.

The research team also conducted semi-structured interviews with private sector connected and automated trucking firms to gauge interest in the TCFC system and expand the number of CV applications. The team attempted to coordinate with related TxDOT research efforts, such as work to support the TxDOT CAV Task Force. However, the timing of this project did not align with the required deadlines for deliverables. The research team contacted representatives from eight automated trucking firms, and three of the eight responded to the inquiry. A major issue with getting respondents to react was staff turnover. Overall, some key findings from the outreach included the following insights:

- Private sector firms felt the TCFC project was the most extensive deployment of CV systems nationwide
- Firms stressed the need for system reliability in regularly providing accurate information (e.g., 99.9 percent accuracy). In other words, trucking operators need to trust the system to gain their participation.
- The emphasis on which CV applications to pursue varied by fleet and travel activity. For example, some trucking firms expressing interest in freight signal priority traveled extensively on signalized arterials, whereas others did not.

For the quantitative assessment, the research team took a data-driven approach that estimated benefit/cost factors, practicality, market adoption likelihood, and level of innovation. The review concluded that TPAS and HRAFTIS had the highest suitability for inclusion within the TCFC system. The TPAS application received high rankings from the Texas Statewide Truck Parking Study and has partnering capability with planned systems on the I-10 corridor between California and Texas. The research team estimated a B/C ratio of 2.8:1 to 4.1:1. The HRAFTIS application has a relatively easier implementation pathway by way of adding high-resolution data to the existing ATIS application, and it has an estimated B/C ratio of 3.6:1 to 8.3:1. Comparatively, the research team did not select the Binational TOC because that application has likely regulatory uncertainty and an estimated B/C ratio of 0.2:1 to 4.7:1.

The research team ended their assessment by expanding the number of CV applications by outlining the next steps for advancing the integration of the truck parking application and adding high-resolution data for traveler information purposes.

For integrating the truck parking application into the TCFC system, the research team identified the following considerations:

- A need to collect real-time data from site locations (i.e., both large and small parking facilities located statewide) and to disseminate these data through a public website and both a state and real-time data feed.
- Implementing a data feed specification will help with disseminating truck parking data. The MAASTO system has an existing specification that could apply to the truck parking application.
- Large parking facilities with 20 or more spaces should use detection that monitors the number of vehicles through entry and exit points. Small parking facilities should use per-space detection technologies.
- Suggested future research needs include analyzing lifecycle costs of detection and parking technologies, electrified parking spaces, and investigating enhanced route planning capabilities (e.g., communicating options when lots fill up).

For integrating high-resolution data into the TCFC system, the research team identified the following considerations:

- The existing DriveTexas service needs to expand to incorporate more granular data. Enhancing the service requires writing additional software that uses existing websites and servers, deploying additional ITS assets, developing complementary mobile applications, and customizing information for individual fleet use.

- Suggested future research needs include analyzing truck-specific movements (i.e., trucks cannot change lanes as fast) because existing probe data do not split the differences between heavy truck and passenger car speeds.

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