# Latest Considerations for Highway and Controlled Environment Freight Automation in Transportation Operations

## Texas CAV Task Force
## Subcommittee on Freight and Delivery

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## Disclaimer

The contents of this white paper reflect the views of the Texas CAV Task Force members, who are responsible for the information presented herein. The contents do not necessarily reflect the official views or policies of the State of Texas or any Texas state agencies. The white paper does not constitute a standard, specification, or regulation, nor does it endorse standards, specifications, or regulations. This white paper does not endorse practices, products, or procedures from any private-sector entity and is presented as a consensus broad opinion document for supporting and enhancing the CAV ecosystem within Texas.

## Texas CAV Task Force Charter

The Texas CAV Task Force was created at the request of Texas Governor Greg Abbott in January 2019. The task force is responsible for preparing Texas for the safe and efficient rollout of CAVs on all forms of transportation infrastructure.

The primary functions are:

1. Coordinating and providing information on CAV technology use and testing in Texas.
2. Informing the public and leaders on current and future CAV advancements and what they mean in Texas. This process includes reporting on the status, future concerns, and how these technologies are changing future quality of life and well-being.
3. Making Texas a leader in understanding how to best prepare and wisely integrate CAV technologies in a positive, safe way, as well as promoting positive development and experiences for the state.

The CAV Task Force is composed of a voting group of no more than 25 members and represents the full spectrum of CAV stakeholders.

## Terminology Note

The Texas CAV Task Force addresses the full spectrum of connected, automated, and autonomous vehicles. An *automated vehicle* refers to a vehicle that may perform a subset of driving tasks and requires a driver to perform the remainder of the driving tasks and supervise each feature's performance while engaged. The performance capabilities of automated and autonomous vehicles consist of levels 0–5 with level 0 having no driving automation and level 5 having full automation, with automation increasing at each progressive level. A fully autonomous vehicle can perform all driving tasks on a sustained basis without the need for a driver to intervene.

These definitions are still blurred in common discussions and language. Currently, the industry is developing automated vehicle capability while pursuing fully autonomous vehicles. The white papers generally use the term *autonomous* to refer to vehicles with fully autonomous capabilities and the term *CAV* to refer to the grouping of connected, automated, and autonomous vehicles. Please see the 2021 terminology white paper for a full listing of terms and definitions used in this developing technology ecosystem.

## List of Terms and Acronyms

| | |
|---|---|
| ATHN | autonomous transfer hub network |
| AV | automated vehicle |
| CAV | connected and autonomous vehicle |
| CDA | cooperative driving automation |
| CV | connected vehicle |
| DOT | department of transportation |
| GDOT | Georgia Department of Transportation |
| MARAD | Maritime Administration |
| MDOT | Maryland Department of Transportation |
| ROW | right of way |
| TCAT | Texas Congestion Analysis Tool |
| TCFC | Texas Connected Freight Corridor |
| TRB | Transportation Research Board |
| TxDOT | Texas Department of Transportation |
| V2I | vehicle to infrastructure |
| V2X | vehicle to everything |

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## Executive Summary

Texas is a leader in the adoption of connected and autonomous vehicle (CAV) technologies, with many companies testing or implementing automated goods movement technologies. It is recognized that the freight ecosystem remains a rapidly changing environment. The Texas Department of Transportation (TxDOT) and partners need to consider the future of emerging freight CAV concepts as it pertains to highway operations. This white paper reviews the latest opportunities, best and emerging practices, and implementation options to support the continued development and support of freight CAV activities in Texas. These activities include:

- Developing a transfer hub/terminal strategic plan: developing an automated trucking transfer hub/terminal strategic plan that includes a thorough evaluation of existing and planned implementation in Texas, how this will impact the freight network, what the development impacts and needs are, and some specific outlining of roles and responsibilities, including support to local governments.
- Assessing Texas Freight Network and automated truck impacts: assessing how automated trucking will change the Texas Freight Network, what infrastructure is needed (including business route optimization, and drayage and circuit identification), what operations coordination would help, and where priority corridors or circuits are that support automated trucking.
- Developing a freight CAV ecosystem: creating an opportunity to share information between the public and private sectors in robust ways; offering ways for the private sector to input activities, and for the public sector to provide data about the freight network, freight facilities, existing freight flows, projects, and more.

While border and law enforcement remain a critical area of concern for freight CAVs, these issues are being studied under different platforms, including the work related to Senate Bill 1308.

The main consideration of this paper is on highway and controlled environment locations. However, many CAV deployments in Texas are in urban areas like Dallas and Austin, and there is potential for activity on resource roads that needs additional research and coordination. The street locations further require in-depth coordination with local governments, as well as discussion of jurisdictional decision-making and how that impacts CAV development decisions.

During the development of this white paper, numerous changes occurred in the companies in the automated truck space. While this paper may refer to a company no longer in existence at the time of publication, it is important to document the activities that have taken place. Steps by companies no longer in the space can still be meaningful to the continued future development of the ecosystem.

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## Introduction

The Freight and Delivery Subcommittee of the Texas Department of Transportation (TxDOT) Connected and Autonomous Vehicles (CAV) Task Force leads the way for TxDOT to support emerging CAV technology implementation in Texas. The CAV Task Force represents public- and private-sector stakeholders who share a common goal of ensuring continued awareness of CAV technology and who support TxDOT in its role to prepare and implement the types of policies, plans, infrastructure, and operations necessary to support current and future technology.

In 2021, the Texas CAV Task Force Freight and Delivery Subcommittee outlined the following questions related to automated freight:

- What would automated freight look like in Texas, and how would it impact border trade and new economic opportunities?
- What are the law enforcement interaction needs related to automated vehicles (AVs) and autonomous trucks?
- What are freight launch pads (transfer hubs or terminals) that allow AV trucks to get on the highway, perform autonomously, and get off the highway? How do they operate? What kind of relationship do they have with the highway network?
- How can TxDOT encourage pilots and trials of automated freight movement? How can TxDOT be a catalyst for the private sector, TxDOT, or federal government to engage in pilots and trials?
- Are hazardous materials allowed? Currently, Texas has no regulations preventing it, but is it something automation companies are looking to do (*1*)?

This document provides an update on the latest in automated freight technology. This paper frames areas of focus and action items for TxDOT and its partners to pursue for planning, policy, and project development for automated trucking. Specifically, this paper seeks to answer questions such as:

- What are the key issues, and how can they be addressed?
- What can TxDOT do to continue to ensure forward-thinking operational opportunities for autonomous trucking?

Texas is already a leader in the adoption of CAV technologies, with many companies testing or implementing automated goods movement technologies and significant research to support development of uses and relationships for CAV related data that supports decision making and system operations. It is important, however, to organize the critical path planning, policy, and project elements that TxDOT and partners should consider for supporting emerging CAV technologies in highway operations. Therefore, this document reviews the latest opportunities, best and emerging practices, and implementation options to support the CAV industry. Furthermore, this paper provides a framework for next steps, actions, and coordination needed based on emerging freight CAV activity. The focus of this document is primarily strategies and updates for TxDOT and its partners to consider in planning and prioritizing actions to support emerging technology. While border and law enforcement interaction remain a critical area of concern for freight CAVs, these issues are being studied under different platforms, including the work related to Senate Bill 1308.

Though Texas is prominent among states that are testing, implementing, and growing CAV technology, TxDOT may wish to consider some new activities in the autonomous trucking space in terms of what the impacts might be to the transportation network and what planning, policies, or projects are needed. These include:

- **Transfer hub and terminal planning:** Automated trucking operations need a point of transfer, and companies are beginning to establish these hubs or terminals. These hubs support connections between automated truck activity. This may consist of human-driven or other automated middle-, first-, and last-mile connections. Hubs will require areas near freight generators and along roadway right of way (ROW), much like traditional truck parking locations do. Truck parking is difficult to develop, and while automated transfer hubs may have a different look, function, and feel, it is important for TxDOT to think about where these hubs might be developed, where there is ROW that could be used, how to transition traditional truck parking to automated terminals over time, and how to strategize and plan with local governments to help support terminal development and tackle some of the challenges that might occur, similar to traditional truck parking.
- **Business route optimization, drayage, and circuit route identification and impacts on planned freight networks**: Business route optimization entails assessing an existing business's operations and identifying how automated trucking could benefit the company and which routes in Texas, as well as transfer points, would best support an optimized network. For TxDOT, the impact might be that the identified freight routes of today may change as optimization makes operations more efficient. TxDOT will want to understand this and how it might impact critical freight routes or how freight routes might be dynamic. Because federal highway funding may be tied to states having fixed freight routes, it is important to understand what optimized routes look like in relation to the existing freight routes and what infrastructure or operational improvements are needed. Additionally, identifying Texas businesses with circuit routes, such as back-and-forth drayage between a port and a warehouse or an agricultural extraction point to a processor and back, might be useful for TxDOT because these locations might be easier opportunities for automation. Understanding where these activities are occurring or could occur can help TxDOT prioritize the best types of improvements or infrastructure. Being able to map and plan for routes with repetitive automated truck movements will help TxDOT work with local governments, especially on first- and last-mile routes, to invest in the type of pavement, intelligent transportation systems, and other infrastructure to support these truck movements and a successful transportation environment for the supply chains depending on them.
- **Continuation of the freight CAV ecosystem data development**: Continuing to support CAVs, particularly automated freight, in developing the ecosystem or transportation network in a comprehensive way that best supports emerging technology will help automated technology thrive. It is important to explore the current and potential investments in infrastructure that TxDOT might want to make that will help develop the CAV ecosystem.

The following sections provide an update on autonomous trucking and operations and information about the latest operations-related activities.

## State of Autonomous Trucking and Operations

Autonomous trucking is dynamic and evolving. Several autonomous trucking companies are delivering freight using their autonomous technology in Texas and throughout the United States today. However, the next few years are expected to show major advancements and implementation efforts, including the first driverless deliveries at scale.

Figure 2 shows the locations of companies identified as recently as November 2022 as key players in the automated trucking space based on a synthesis by the industry publication *Transport Topics* on top companies involved in automated trucking. Some of the companies operating in Texas include:

- Aurora,
- Einride,
- Embark (now defunct),
- Gatik,
- Kodiak,
- Waymo,
- Torc Robotics, and
- TuSimple (*2*).

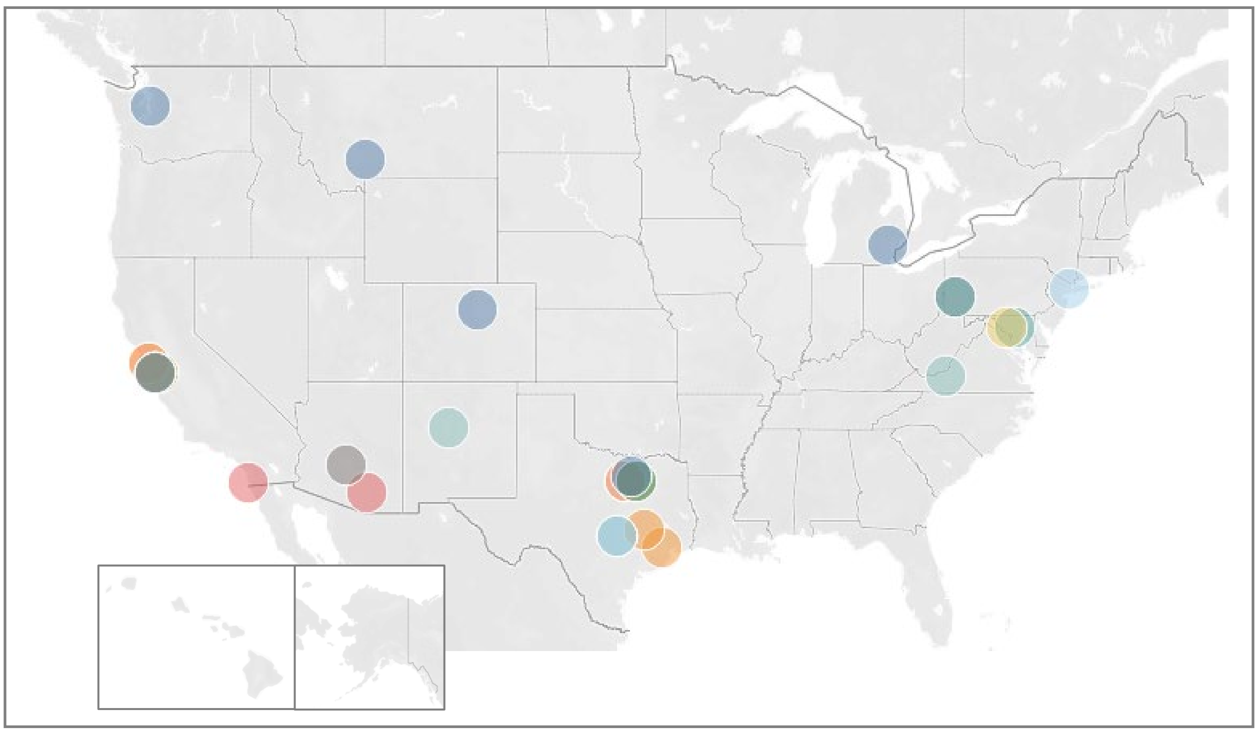

*Figure 1: Locations of Companies in the United States Involved in Autonomous Trucking*

Many of these companies focus on systems that provide automated truck activities for long-haul, hub-to-hub movements, but several also focus on short-haul operations with lighter-truck usage (2). Many partner with major trucking companies like Werner, Schneider, and Ryder, as well as major retail and manufacturing establishments like General Electric. Some have even delivered mail for the United States Postal Service (2).

Recent meetings on automated transportation bringing together leaders in the CAV space have attempted to categorize and synthesize all the rapid growth of CAVs, especially with freight movement (specifically meetings sponsored by the Transportation Research Board [TRB]). These meetings have been an important part of bringing together the CAV industry with state departments of transportation (DOTs) to discuss the types of plans, policies, and projects that need focus for automation to grow.

For example, presentations from the recent gathering of stakeholders sponsored by TRB summarized the following points:

- Deployment of freight autonomous trucks is happening, but more is expected by 2024. There are currently limited operations without safety drivers, but more is expected in the next few years.
- This deployment is expected to especially impact long haul freight links. This trend means that automated freight activity will mostly take place on interstates and key highways with the use of transfer hubs to switch to human drivers for first- and last-mile connections because these are simpler operating environments than other roadways like busy urban streets.
- The CAV industry expects significant benefits regarding safety, efficiency, sustainability, fuel, and refrigeration of perishable goods. An additional expectation is a reduction of driver turnover and job satisfaction issues. This can also lead to improved customer satisfaction.
- It will be important to understand how to implement frameworks for inspections and handling of roadside processes with autonomous trucks by state and local safety personnel. The Commercial Vehicle Safety Alliance has made considerable progress towards developing processes to accommodate autonomous trucks.
- Many state and federal efforts assess off-highway freight operations for automated driver systems, but some of the technology is still getting started. By far, the focus is on-highway operations. It will be critical to establish broad public/private-sector partnerships for vehicle approval and safety reporting processes going forward (*3*).

In addition, while freight CAVs have been considered mostly at the long-haul, interstate level, there is recognition that freight CAVs are growing in several types of freight-centric locations (*4*). The following are four key location examples to consider in freight planning and CAV implementation:

- **Controlled environments** (e.g., ports, warehouse and distribution centers, and intermodal facilities): These locations are contained and may already have automation in place (e.g., robotic cranes). Characteristics include:
    - Low speed operations and
    - Dirty and dusty environments (important to consider for sensors and camera use).
- **Streets** (e.g., urban areas, suburban streets, and a strong mix of activities and modes [bike and pedestrian with urban delivery]): Characteristics include:
    - A complex environment (a lot of different elements),

  - Low- to medium-speed movement,
  - Customer facing (in this environment, the freight is usually going directly to the end user), and
  - A strong market and growing (things like e-commerce are growing the day-to-day demand for freight delivery).

- **Resource roads** (i.e., access to facilities like oil and gas, forests, and agriculture): Characteristics include:
  - Unpaved roads typically,
  - Remote areas,
  - Medium-speed movements, and
  - A modest market for automation currently.

- **Highways** (i.e., interstates and major roadways): Characteristics include:
  - A well-ordered environment (i.e., not complex like urban streets),
  - High-speed movements, and
  - A huge market (one of the largest opportunities for autonomous trucks now).

The focus for this paper is the highway and controlled environment locations. However, many CAV deployments in Texas are in urban areas like Dallas, and there is potential for activity on resource roads that needs additional research and coordination. The street locations further require in-depth coordination with local governments, and discussion of jurisdictional decision-making and how that impacts AV development decisions.

## Latest Considerations for Freight CAV and Operations Activities

Given the state of the practice as described previously, this section provides details about the latest areas of focus for operations and freight CAVs. The focus is primarily autonomous trucks, but some connected vehicle (CV) information is included.

### *Developing a Transfer Hub/Terminal Strategic Plan*

The concept of autonomous trucking launchpads or connection points is primarily to support autonomous trucking freight/trailer exchanges. The vehicle would be a conventional (human-driven) truck. It could also be a robot that has either picked up freight to deliver for over-the-road carriage or that is receiving freight to take to a local destination. Autonomous trucks would carry freight in between hubs, and conventional trucks with human drivers would handle the first- and last-mile operations. Transfer hubs would work by applying automation on highway stretches, while humans would continue with more complex and local driving and customer contact.

Companies estimate that an autonomous truck and transfer hub system would provide an operational cost savings from 22 to 40 percent (2). This estimate is based on the cost difference between driverless trucks and conventional trucks. Additionally, companies are assuming this kind of setup would work for roadway segments where there are driver-related (human) issues such as high turnover.

To work, however, freight transfer hubs would require establishment of “drop yards near interstates” where transfers of cargo (trailer transfers) could take place. The hubs would require ROW along highways and at major arterial access points to interstates that lead to and from freight generators to support full-scale implementation (2).

In the past year or two, companies in the automated trucking space have discussed the property needed to support these hubs. Some companies would build their own transfer facilities, while others would rely on existing built facilities and retrofit for autonomous trucking transfer operations. Major intermodal players, including Alliance Texas, have also explored how to build open-access truck ports near their key operations hubs. Some companies describe a goal of not needing these transfer hubs once trucks are fully autonomous, but for now, the transfer hubs help propel the autonomous truck technology (2).

This is a rapidly changing environment as during the development of this document, the types of companies in the automated truck space have changed, either starting up or becoming defunct. However, it is important to document the activities that have taken place, even if involving a defunct company, because the steps taken toward automated trucking operations appear to still be important, such as developing a network and transfer hubs.

For example, Ryder is a company that is working with several autonomous trucking companies to develop transfer networks and autonomous truck facilities throughout the United States. Ryder was planning logistics networks with Embark, a former autonomous trucking company, which would have included transfer points or hubs. This partnership was expected to produce a nationwide network of up to 100 transfer points. Ryder still has plans to help Waymo Via scale its autonomous trucking business by helping with standardized fleet maintenance and management. Further, Ryder and TuSimple are leveraging Ryder facilities as terminals for TuSimple (5).

Ryder is also working with Gatik, a company engaged in automating on-road transportation for short-haul and middle-mile logistics. Through this partnership, Gatik will lease a fleet of medium-duty, multi-temperature box trucks to support goods distribution to retail that supports e-commerce. According to Ryder, “Gatik will integrate its commercial-grade autonomous driving technology into the leased fleet, enabling Gatik to provide its Autonomous Delivery as a Service (ADaaS) model to its new and existing customers.” Ryder will both provide the leased vehicles and service the trucks including autonomous components. The initial focus of this is in the Dallas/Fort Worth area (6).

The reason that a company like Ryder is engaging in these business relationships is that it has large facilities for maintenance and a network of supply chain and logistics centers. Ryder will provide yard operations, maintenance, and fleet management and will provide advisory input on transfer points where freight will be moved from driverless long-haul trucks to driver-controlled trucks for first- and last-mile deliveries.

Waymo is another company that built a hub for autonomous trucking. The Waymo hub in Dallas is 9 acres and serves as Waymo’s primary operations center in Texas. The hub supports operations and testing and connects to Waymo’s operations center in Arizona. Waymo’s point of view is that these hub facilities must be large. The company says that a facility needs to support hundreds of people and trucks (7).

Additionally, TuSimple is teaming up with Hillwood, which is a large industrial and commercial real estate developer, to develop commercial properties that integrate the autonomous truck infrastructure specifications (*8*). TuSimple and Hillwood are starting with a 1-million-square-foot facility in Hillwood's 27,000-square-acre Alliance Texas development in the Dallas/Fort Worth area. Alliance Texas provides an ecosystem that can support testing of new technology to adopt, integrate, and scale level 4 autonomous truck operations. The facility is located off I-35 near the Fort Worth Alliance Airport, major freight partner facilities such as UPS and DHL, and major distribution centers (8).

Little information is publicly available on what resources, space, and development capabilities are needed to support these transfer hubs, and more research is needed to understand the demand on the transportation network. It will be critical to understand the spatial needs, footprints, and potential impacts because implementing a transfer hub network could make major changes to the existing transportation system and create demands such as access to roadways and utilities, impacts on traffic patterns, and more. Most of the research points to outfitting Class 8 trucks, so this would be the primary size for these sorts of transfer hubs. Other types of autonomous freight vehicles like urban delivery hubs will need a different model.

An important element is understanding how to work with local governments and communities to obtain the necessary zoning and support. These hubs are an evolution of the truck parking issue that exists throughout the United States. Truck parking is notoriously difficult to develop and is often met with community opposition. Texas could have a role in working with local governments and industries to negotiate the best solutions for these facilities.

Another consideration is how other efforts in the AV space will work to support freight needs like transfer hubs. There are efforts to use traffic signal CV technology to improve the flow of freight vehicles through signalized intersections, which may help optimize flow of freight vehicles in and out of transfer hubs and expressways. It is necessary to look at transfer hubs as part of the surrounding system to understand the flow of traffic and how transfer hubs connect.

In addition to the transfer hub model helping companies achieve efficiencies in freight flow, transfer hubs would also support some of the driver issues that exist in the trucking industry. If autonomous trucks handle the long-haul leg of freight trips, driver jobs would be more local or regional and short haul, allowing for more home time (2).

There is an emphasis for companies in this space to build off-highway transfer hubs as an essential function to support autonomous trucking. It may be important to support this requirement by having TxDOT identify property, especially state-owned ROW, and preserve it, which is akin to the preservation of ROW for highway and transit projects (i.e., rail banking and property banking). Identifying, acquiring, and preserving ROW are difficult and costly—yet necessary—tasks for DOTs, and the acquisition of transfer hub property is also expected to require capital and time to develop (2).

### Implications for Operations

The transfer hub and network development may create several impacts for DOT operations, such as:

- Networks may change travel patterns and freight flows.

- Coordination with local governments will be critical for developing or adapting existing areas for transfer hubs. It will also be important to explore how freight is broken down further, such as for urban delivery.
- DOTs may want to catalogue and grade available state-owned property, especially highway ROW, to support transfer facilities. This may be useful in efforts to see autonomous trucking grow, especially where facilities are needed that will be in or near highway ROW.
- DOTs may want to catalogue or hold property, as well as invest in or negotiate property, to support transfer hubs, especially near highways. This state-owned property may also be useful in developing public-private partnership arrangements and/or as match for funding opportunities.

The Maryland Department of Transportation (MDOT), for example, is doing something similar for truck parking. MDOT has assessed all state-owned excess property that MDOT would normally try to sell or that is highway adjacent with low land use potential for capability to support truck parking. MDOT graded each property using a set of criteria and then whittled down top candidates. MDOT uses an ArcGIS online app to show the properties in relation to truck traffic and industrial access (*9*).

A similar activity to MDOT could take place with TxDOT or State of Texas properties to assess which properties might support freight operations and transfer hubs, and to determine which ones should be banked. Additionally, this work could engage economic development entities and the private sector to offer potential properties for sale to support private autonomous freight trucking operations. In other words, it is important to think through how to get existing truck parking AV ready, and this may accelerate the development of automated trucking and related technologies.

### Potential Activities to Further Developing a Transfer Hub/Terminal Strategic Plan

The following questions outline some of the potential activities to consider related to furthering the development of a transfer hub/terminal strategic plan:

- **How will the freight network change with new autonomous trucking networks, and where will these transfer hubs be needed?** While it may be impossible to know exactly where companies may build transfer hubs, it might be useful to assess where Ryder locations are in relation to Texas' network and to then use existing tools such as the Texas 100 Most Congested Roadways and the Texas Congestion Analysis Tool (TCAT) to understand freight mobility in their areas. Then, an assessment of future conditions could be done to understand the impact of increased truck activity, including a look at potential congestion, safety, and asset conditions. Having the ability to run scenarios of how the networks will change will help in discussions with regions and local governments about prioritizing projects or in deploying operational treatments.
- **Does TxDOT or the State of Texas have property along highway ROW that could support autonomous trucking?** A good exercise might be to catalogue state-owned property and determine where potentially suitable transfer hub property exists that could support transfer hub activity. There might be opportunities to sell excess property to private-sector interests, to use it in negotiating public-private partnerships, or to offer it as a match for funding programs.

## *Assessing Texas Freight Network and Automated Truck Impacts*

A precursor activity for autonomous trucking companies is identifying optimum routes. This might be based on existing freight flows or potential future freight flows. This type of analysis would help to guide implementation and advancement of autonomous trucking to achieve optimum cost savings.

Ryder System, Inc., and the Georgia Institute of Technology worked together to assess Ryder's business routes and how autonomous trucking would provide a cost savings based on route optimization. Georgia Tech used real-world data from Ryder's dedicated transportation network in the Southeast and developed an autonomous transfer hub network (ATHN) that combines autonomous trucks on highways with conventional trucking operations for the first and final miles. Then, Georgia Tech introduced optimization models for routing and dispatching autonomous trucks. This was evaluated by comparing the ATHN with existing operations under different assumptions (*10*).

Georgia Tech found that the ATHN with optimization technology can reduce costs by 29 to 40 percent for a large network, depending on the price of the trucks and the direct and indirect costs of operating them. The lead researcher, Dr. Pascal Van Hentenryck of Georgia Tech, noted, "In the transfer hub network, there is no need to return back after a delivery, and there is no need to limit working hours or return to a domicile at the end of the day. As a result, only 35% of the automated distance is driven empty, compared to 50%. This means that even if autonomous trucks would be as expensive as trucks with drivers, costs would still go down by 10%" (10). Further, Georgia Tech found additional savings from reduced labor costs and idle time. Benefits also include increased flexibility in delivery appointments to keep autonomous trucks moving all the time (10).

The useful outcome from this type of work for DOT operations is the potential for DOTs to work with private-sector stakeholders to understand route optimization and where those routes would be, along with the required infrastructure such as transfer hubs to support those routes. DOTs could compare the autonomous trucking optimized routes to existing freight plans and freight performance information to determine how they match and what the automated network looks like, if different from the existing prioritized freight network. Then, decisions and investments could be made to determine if more capacity is needed or how to deploy use of operational treatments to facilitate the freight flow.

A focus for using autonomous truck technology is to support routes that are circuits such as drayage to and from a port or trucks that carry freight back and forth between parts of a factory or processing plant. Research is beginning to show ways that companies are looking at these routes and targeting them for use of automation.

The United States Department of Transportation Maritime Administration (MARAD) is also working on port drayage with cooperative driving automation (CDA) technologies. The goal is for CDA to improve port performance and involves development and testing of use cases for port drayage and commercial motor vehicle operations that leverage CDA-equipped commercial vehicles to increase efficiency and safety while decreasing emissions. MARAD hopes that the work will advance the adoption of CAVs and CDA technology for U.S. ports and that there will be more information about the benefits and costs of CAVs and CDA in port areas. The project started in 2019 with a goal of completion in 2022 (*11*).

## Implications for Operations

Again, the key issue here is understanding how the freight network is going to change. If companies adopt autonomous operations (which they will if there is a cost savings and increased efficiency), how will they optimize the use of these vehicles? Where will they place terminals? How will those terminals change existing freight flows? These are critical questions to research, plan, and incorporate into the statewide freight plan and to develop more specifically region to region.

A challenge will be knowing what those optimized routes look like, especially if the private sector is unwilling to share or provide details. Strong partnerships and conversations may help navigate some of these issues, and perhaps the private sector will advocate for their routes and transfer hub locations so that TxDOT can support improved freight flow to these facilities.

TxDOT's system operators, especially in districts, should expect that as automation matures, the network will change. In this case, there might be dedicated routes for platooning or automated trucks to move freight in a circuit. If this is the case, this may impact the current network setup and asset condition. There is some concern for pavement condition from repeated truck operations, so these sections may need to be improved for the trucks the road will support if there is growth or concentration of truck activity to a particularly efficient route. In addition, system operators may need to adjust roadway tools and practices and establish strong coordination with local governments because first- and last-mile connections are likely local roadways.

Some research is available on the pavement issue. Since circuits have the potential to be optimized as well-traveled autonomous truck routes, pavement condition challenges are likely. For example, research that analyzed the trade-off between fuel savings and pavement fatigue found that a slight lateral offset of the trucks (100 to 150 mm) would reduce pavement damage by 30 percent while maintaining a fuel savings of 8 percent (*12*). Assessments will be needed to determine the impact to the roadway network and how slight changes in the operation of platoons or autonomous truck circuits can offset asset decline.

## Potential Activities to Further Assessing Texas Freight Networks and Automated Truck Impacts

It is important to understand existing and future freight flows more than ever and to plan for changes, especially on the parts of the freight network that TxDOT can best control. Parts of any supply chain will be fully operated by the private sector. However, understanding what is expected on the Texas Freight Network will help determine the types of capacity and infrastructure needs or operational treatments.

An important planning activity is assessing existing and future freight flows in the statewide freight plan and engaging Texas industries about how they might be thinking of optimizing routes for autonomous trucking. The answer may be unknown by many or well known by some, but the dialogue needs to begin. Perhaps TxDOT can commission an assessment of how the existing freight flows and performance might change with expected changes in routes.

In addition to planning, TxDOT maintains several resources such as its TCAT. These tools and newer freight fluidity tools available can help assess freight networks and tie commodities and industries to networks in ways TxDOT has not been able to do before. This will help TxDOT know where the key routes are, what commodities they support, and the user (business) experiences on Texas' roadways.

Therefore, continuing these resources and using them ubiquitously can help improve awareness of the existing freight networks. Use can help identify points that might change or shift when autonomous trucks saturate the network.

One starting point for drayage and circuits is evaluating truck flows at key freight locations. It is possible to use truck probe data to assess the truck activity and identify drayage and circuit operations that may be best targeted for autonomous trucks or platooning.

Another planning activity would be to work with TxDOT district staff to identify these routes and what might need to be considered from an operational perspective that would support freight movement while ensuring safety, efficiency, and environmental improvements. For example, repeatable routes that can be pre-mapped will be the easiest to use for autonomy in the near term. Judging the complexity of the routes, such as by speed, intersections, unique features, traffic density, etc., will also affect autonomous vehicle implementation. Companies may make different judgments about the complexity of routes, given their technologies.

It may also be important that operations staff work with TxDOT planning, asset management, and pavement staff to research ways to offset asset decline or optimize asset performance given new, repetitive levels of activity on these segments.

### *Developing a Freight CAV Ecosystem*

Texas is one of the key states in the nation developing the concept of CAV ecosystems in which CAVs can grow and thrive. Texas has the Texas Connected Freight Corridor (TCFC), which is a collaborative effort with public and private stakeholders to deploy CV technology to more than 400 commercial and TxDOT fleet vehicles to improve freight movement and increase safety for all road users. The goal is to help long-haul freight and infrastructure communicate to optimize safety and freight mobility (1).

The current scope of the TCFC is the 865-mile Texas Triangle of I-35 (including an extension to Laredo), I-45 (linking Houston to Dallas-Fort Worth), I-10(connecting Houston with San Antonio), and the I-30 technology corridor between Dallas and Fort Worth.

Some of the short-term activities envisioned by the TCFC are that trucks operated by companies partnering with TxDOT will receive more timely and accurate information about traffic and roadway conditions. Receiving these alerts is expected to help improve safety and efficiency. Plans are to incorporate smarter traffic intersections around distribution centers to help improve freight flow and reduce idling. In the long term, the TCFC will transfer technology to other Texas freight corridors to help improve freight flows, safety, and environmental impacts (1). As part of the TCFC, TxDOT created the Connected Vehicle Data Framework (CVDF) with a goal of reducing physical intelligent transportation system (ITS) infrastructure and mediating coverage with a cloud-based option and data exchange that relies on cellular coverage and existing third-party services (*13*). TxDOT is expanding the CVDF through research to leverage existing CVDF for the TCFC to expand its efficacy through applications, data partners, and corridors. This will help create new benefits like improved real-time traveler information, increased adoption in freight markets, and strategic infrastructure investments (*14*).

Another similar project is the I-35 Traveler Information During Construction project. The purpose of this project is to create a connected work zone for enhanced traveler information. Using the data from the I-35 traveler information initiative, the first phase provides advanced freight traveler information for pre-trip and en-route planning to participating freight carriers. The information conveyed to dispatchers and vehicle cabs includes work zone closure locations, capacity reductions, queue lengths, and delay. The second phase of the project develops and deploys a connected work zone using 5.9-GHz vehicle-to-infrastructure (V2I) communication and dedicated short-range communication to warn of work zone locations, delays, and traffic queues. The work zone testing includes mapping procedures and both low- and high-fidelity work zone information transfer to vehicle onboard units (*15*).

In addition, there is much discussion and new research focused on CVs and vehicle-to-vehicle and V2I communications throughout the state. Many of the discussions focus on feeding information to drivers (passenger and freight) and having infrastructure, vehicles, and other information systems (e.g., weather) all in communication for a safer and more efficient experience on the transportation network.

One area that TxDOT has explored and that should be continued is the collection of data from V2I vehicles that can support DOT decision-making. For example, do the sensor and camera data collected by automated trucks have utility if shared (anonymously or in aggregate) with a DOT where the DOT can use the information to understand the freight user experience on the network? This information, such as pavement condition, performance during various weather conditions, autonomous truck perception of roadway markings and signs, the capture of the spatial placement of roadway features, and the vehicle's perception and maneuvering around other vehicles, bicycles, and pedestrians, would all be useful information for a DOT to support its role in collecting or overseeing operations for things like:

- Asset condition information for asset management;
- Roadway features;
- Equipment placement (barrels and cones);
- Detours;
- Traffic mix and freight vehicle interaction with other vehicles, bicycles, and pedestrians;
- Incident response; and
- Transportation system management operations treatments.

There are two TxDOT projects focused on using data and images from automated trucks to improve routine maintenance operations. One project is the RTI Project 0-7129 led by the University of Texas at Austin Center for Transportation Research. This research will test and end-to-end Intelligent Routine Maintenance Framework through use of real-time data on pavement, signage and other assets that can help to modernize maintenance operations (*16*). Another project is part of the Texas Connected Freight Corridor (TCFC) I-30 Supplementary Project led by the Texas A&M Transportation Institute to expand on the existing TCFC applications and explore options for using collected data in decision-making.

In addition, a wealth of data comes from CVs and can help support DOT decision-making, especially for freight. Some companies like Wejo, Kodiak, and General Motors are making some of the CV data available. Initial discussions and tests are taking place (17). TxDOT has a data sharing contract in place, and this provides a platform for growth in data services and support for decision making.

There are additional efforts to grow data sharing opportunities and exchanges with CV data worth noting. One is the Texas Work Zone Data Exchange Dataset. TxDOT's highway system provides land closure information to the Federal Highway Administration (FHWA) Work Zone Data Exchange (WZDx). The WZDx is a cooperative effort led by the United States Department of Transportation (USDOT) and stakeholders to share work zone data and make it available for third-party users. These users include mapping companies, vehicle manufacturers, and automated vehicles. Work zones are especially difficult for trucks, so FHWA is hoping that by collaborating on the exchange of work zone data, this will support the advancement of existing trucking operations and future automated activities (18).

Another is the North Central Texas Council of Governments (NCTCOG), which selected Blyncsy, Inc. to supply a situational awareness app testing sandbox with a goal of understanding how CV data can help in real time to support operations, safety, and decision making (19). Blyncsy Inc. was selected to support the sandbox beginning with monitoring work zones in real time. Blyncsy will provide its data to the Federal Highway Administration (FHWA) Work Zone Data Exchange (WZDx data feed). "Harmonized work zone data will be available for third-party use as part of the Work Zone Data Exchange. The new ability to openly share work zone data from roads will increase safety and efficiency for drivers, construction workers, and transportation employees and provide critical data to advance the upcoming development of autonomous vehicles. The date comes from Blyncys' Payver technology, which leverages "artificial intelligence and crowdsourced visual imagery from dashcams to provide automated work zone surveys" (20).

### Examples of Ecosystem Development in Other Locations

Some recent advancements in the development of an ecosystem and data/vehicle-to-everything (V2X) analytics include projects out of Georgia. Like Texas, the Georgia Department of Transportation (GDOT) has set up a testbed for CAV technology called the Ray (which is broader than the TCFC), which has a goal to provide data to support operations among many other critical transportation goals. For example, the Ray is proposed as a zero-carbon, zero-waste, zero-death highway system, and GDOT has partnered with companies like 3M to test various technologies to support this. Figure 4 shows a graphic from the Ray's website about its V2X vision (*21*). The Ray is an 18-mile stretch of I-85 in southwest Georgia. Primarily, the testing involves smart road infrastructure such as:

- In-road and roadside connected infrastructure that communicates with vehicles in an evolving capacity (as technology evolves). The communication should provide GDOT with real-time, location-specific data from vehicles to improve safety, ease congestion, and identify maintenance needs.
- Smart road markers that are solar powered and convey different alerts to drivers such as incidents and wrong-way driving. The markers are dynamic and can help inform and direct traffic.

- Digital data management platforms that work to analyze and articulate data collected by the smart infrastructure so that the data can be used by law enforcement, first responders, and traffic safety officials (15).

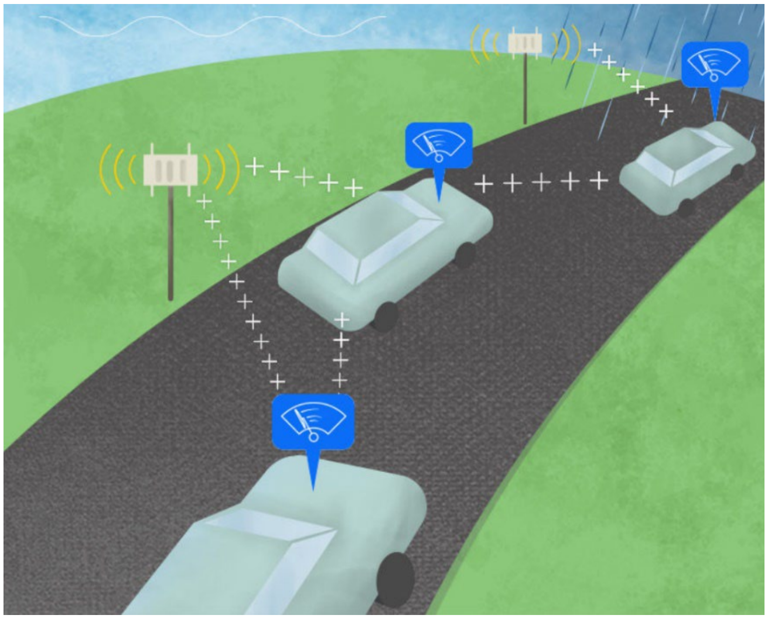

*Figure 2: Illustration of Vehicle-to-Infrastructure Technology*

Another element of a freight ecosystem is signal prioritization. GDOT has had success in the past decade using signal prioritization in operations. GDOT has established regional coordination to proactively manage and maintain traffic signals statewide (*22*).

GDOT is now working with freight operators to implement freight signal priority. GDOT is working on a pilot that will provide the same operational benefit as transit vehicles to freight operators in port areas. The goal is to improve freight movements to and from ports, but GDOT has identified future options such as supporting autonomous trucks on highways and platoons.

Finally, GDOT is developing a concept design for the I-75 Commercial Vehicle Lanes project under GDOT's Major Mobility Investment Program. This project is expected to produce recommendations for operations impacts and actions to support autonomous trucks and commercial vehicle lanes that TxDOT will want to consider (*23*).

## Implications for Operations

Evolving to a new transportation ecosystem will change the roles, resources, and practices of any transportation system operations staff. Everything is changing, and technology is making it possible to do more than ever before to support emerging technology that is expected to help safety, efficiency, the environment, and more.

Some opportunities relevant for operations include:

- Expand TxDOT's Connected Vehicle Data Framework (CVDF) – a two-way data exchange – to support the system operators and decision-makers, autonomous trucking, and conventional trucking. Collect data to inform real-time operations and longer-term planning.

- Stay up on all communications technology development and the resources needed to support it. Understand what is emerging and try to develop an ecosystem that can adapt.
- Review and/or establish and update operational procedures that can be flexible with technology as it evolves. Ensure the procedures work with autonomous trucking and conventional trucking for now. Consider incident management and inspection procedures to facilitate autonomous trucking.
- Determine cost versus benefit of outfitting the network with sensors and devices to have as much opportunity as necessary to collect freight user experience and determine ways to use that information to provide to autonomous trucks and conventional drivers. Partnerships will be necessary with autonomous trucking companies to determine the data feeds their technology can use to ensure safe and efficient operations.
- Assess V2X technology data reliability. Understand the data's limitations for automated trucking and identify gaps and ways partners can work to improve the data.

### Potential Activities to Further Developing a Freight CAV Ecosystem

Texas is already considering many, if not all, of these recommended actions and is implementing the ecosystem that states are seeking. In fact, Texas is a leader. However, Texas can work toward automated trucking development by considering some of the following:

- Continue testing V2I data for state DOT decision-making purposes related to automated trucking, as described above. Identify what is useful, what kinds of intel the data provide, and the best way to access and process the data. This will require some pilots and experiments with companies willing to share data. Tesla, for example, picks up asset elements (e.g., road barrels, cones, traffic lights, guard rails, and mixed traffic) for its drivers. These data have value for DOTs and may help DOTs optimize the information the DOTs have available to improve the network for safety, efficiency, asset maintenance, and more. Current activities throughout the states are looking at data sharing and evaluating the utility of various types of CV data, so this would build on these efforts. Review, update, and establish new operational procedures for inspections, incident management, routing, etc. that work with autonomous trucking as they do with conventional vehicles. Consider how anything might need to change, what data feeds are needed, and what format is needed for messaging the driving community.

## *Additional Findings*

In addition, a few key efforts are under way in other states and internationally that might be important for operations staff to consider.

### Public Acceptance

Many of the articles and resources used for this paper have mentioned public acceptance. Discussions speak about needing to get the public comfortable with autonomous, as well as other automation, in addition to all the things described like developing transfer hubs. Considering the public-facing side of this may be an important activity for TxDOT as it seeks to advance autonomous trucking operations in the state.

For example, public acceptance of platooning semi-automated trucks in Germany and California was studied and compared. Some interesting insights are as follows:

- Most responders (70 percent) from both areas have a positive attitude toward truck platooning driving (technology acceptance).
- The primary concerns of sharing the road with platooning vehicles is the reliability of technology, followed by problems when entering/exiting highways and issues with cut-in vehicles.
- There may be differences culturally in what people perceive as a safe gap between vehicles, and this may be worth exploring in setting standards.
- Expected usefulness and expected ease of sharing were the most influential factors in attitudes toward sharing the road.
- Negative attitudes to regular (conventional) truck drivers were related to the positive perceived ease of road sharing with platooning trucks. This means that the more people disliked conventional trucks, the more positive expectation for having to interact with semi-automated truck platoons (*24*).

TxDOT may wish to get a head start on the public coordination and acceptance of autonomous trucking including the changes in expected networks and development of transfer hubs. This may need to involve public information campaigns, community outreach, and coordination with planning entities and elected officials.

### Automated Trucks and Border-Crossing Transfer Hubs

While this paper does not include border crossing as a focus, recent research has some findings that TxDOT may wish to review in its parallel border-crossing freight CAV work.

First, the Ciudad Juarez bi-national metropolitan area has been proposed as part of a smart city because it includes one of the largest international trade crossings in the United States. The border connection between El Paso, Texas, and Ciudad Juarez, Mexico, has growing freight congestion. Research on autonomous truck operations around the border proposes several ideas:

- Apply the autonomous truck system to smart logistics border planning such that autonomous trucks can transfer cargo across the border and the general entry process that requires documentation and review can be negated. This may include transfer hubs at the border.
- To support automated truck operations, provide a high-speed data network to support V2I or V2X communications and traffic signal control at the border.
- Separate trucks from personal vehicles and pedestrians when crossing the bridge at the border and establish a transfer hub for autonomous trucks.
- Potentially implement a conveyor system to transfer products at the border, which may require a partnership of public- and private-sector stakeholders along with proper security from both the United States and Mexican customs agencies (*25*).
- Coordinate with Border Patrol to create processes for autonomous trucks in the border zone.

Build an open-access truckport that will allow for autonomous trucks to efficiently service border trade.Other research coming out of Canada for the northern border focused on border crossings and automated trucks by raising several concerns that United States–Mexican crossings may also experience:

- **Challenges of managing the importing process:** The normal customs process is now mostly digital with documents completed electronically. However, drivers are often asked questions when border agents have questions or concerns. Researchers propose trying to increase the information provided in electronic documents available to border officials ahead of the truck's arrival at the border, but researchers recognize that many security and safety concerns cannot be mitigated that way and require in-person, visual inspection, and observation.
- **Navigation through inspection plazas:** Many border inspection plazas are not easy to maneuver through, and it will be important to test autonomous truck technology's ability to navigate them. Additionally, when there are many autonomous trucks are coming through, it will be necessary to rethink border plazas both physically and technologically. Secure intelligent transportation systems and networks will need to be in place to not only ensure safe navigation but also prevent cybersecurity threats (*26*).

## Focus Areas and Actions Necessary to Support DOT Operations for Automated Trucking

Freight CAVs are a dynamic area. Things are changing rapidly. The technology of today will be quickly outdated, and the transportation network in place now may significantly change to accommodate the growth of freight automation, especially if the estimated benefits are realized in initial pilots and implementation efforts.

It is important to identify areas of focus and specific actions for the immediate future for what the State of Texas can do to facilitate automated trucking. While it is helpful to identify longer-term items, these may be less specific and more general due to the dynamics of automated technology.

Based on the state of the CAV industry and current rollout of automated trucking activity, several areas are important for TxDOT and its partners to consider in the immediate future (Figure 5). These are:

- **Transfer hubs/terminals:** What is the state's role?
- **The Texas Freight Network:** How will the network change? What are the impacts of automation? Are there key routes or circuits to prioritize?
- **Development of a freight automated ecosystem:** How can the state support testing and implementation? What information is needed?

**State's role in transfer hubs**

- Is this the new truck parking?
- How can we set up for success?
- Where are these hubs needed?

**State's role in the freight network**

- Provide information about the National Highway Freight Network (NHFN)
- Discuss how freight route optimization might impact the NHFN
- Identify areas where automation can be easily implemented (routes, circuits, and drayage)

**State's role in the ecosystem**

- Set up an information repository—who is doing what in Texas?
- Identify key efforts throughout the state
- Identify and support pilots, testing, or implementation for freight projects

*Figure 3: Immediate Areas of Focus for Automated Trucking in Texas*

### *Developing a Transfer Hub/Terminal Strategic Plan*

Based on the findings, automated trucking requires a point of connection to transfer freight, charge vehicles, and perform maintenance. The industry has described these hubs in several ways:

- **Privately built** serving only one company,
- **Open source:** an opportunity to serve many, and
- **Public:** publicly supported (like public truck parking).

In addition, the way these are being developed appears to fall into the following categories:

- **Industrial property:** using existing areas or properties already involved in intermodal or warehouse/distribution or other transfer facilities, and
- **New industrial facilities:** developing new facilities and siting new properties.

However, other options appear less explored. These include:

- **Existing truck parking:** identifying ways to evolve existing truck parking to automated truck terminals, and
- **New truck parking/transfer hubs:** developing new parking/transfer locations since existing truck parking is in short supply.

The way these terminals are beginning to develop seems to serve the automated trucking companies individually, despite discussions of open-source options. Reports show companies developing terminals or using existing properties by converting locations.

It will be important to identify the state's role in terminal development. For example, will the state need strategies to work with local governments on planning and zoning to ensure successful development of an automated network. The state can help determine where these hubs are needed and where property and partnerships may support hub development. Identifying the state's role raises several questions. First, is the development of these transfer hubs like the efforts underway to identify electric vehicle charging locations, and is there a government role in planning and siting these locations? Tesla, for example, led the development of a robust charging network, and there are fewer other charging options. Tesla plans to open its charging network to other electric vehicles, and the federal government plans to invest in developing more electric vehicle charging options.

Like the electric vehicle charging network situation, automated trucking companies are developing their own networks of terminals (which may also be charging stations). Will this create a situation of winners and losers depending on who can establish transfer points quicker and in the most advantageous locations for freight mobility? Is there a need for TxDOT to understand this or to have a sense of how and where these hubs are developing, if they are private, open source, or both, and if there needs to be public support of hubs? TxDOT investments may be best focused on drawing autonomous trucks to strategically important corridors, particularly on the border in line with TxDOT's plans for the "Third Coast" strategy to develop Texas ports as the third national international, maritime gateway (*27*).

It is important to explore this development in further detail and determine the public-sector role. It is critical to understand how and where companies are establishing these terminals and who gets to use them. Support may be needed for an open-source market of terminals or even publicly supported terminals.

Similarly, development of these transfer hubs appears to have occurred or is being planned with little or no opposition. However, truck parking development for human-driven trucks receives significant opposition. Even though these transfer hubs serve a function to transfer containers or charge, they are a form of truck parking and trucking operations, which historically receives community opposition even when sited in industrial areas. The Federal Highway Administration Jason's Law report from 2015 and 2019 found that community opposition was a major reason truck parking does not get built and a shortage exists.

As the need for transfer points grows throughout Texas, it is important to understand where these locations might be sited, what existing facilities might be retrofitted, and what the trucking activity looks like, as well as if there is a role in the state working with impacted local governments to support the development and mitigating community impacts where needed. It may be necessary to look at the freight network to identify important locations for transfer operations, assess what kinds of existing property or ROW exists, evaluate what might be needed, and develop a strategy with those operating in Texas to retrofit and/or site these truck terminals.

Therefore, the following specific actions are recommended related to transfer hub development:

- Develop understanding of existing plans by companies operating in Texas.
- Evaluate private versus open source and the potential impacts or issues.
- Develop understanding of freight flows and the freight network, as well as where it makes sense to have transfer hubs.
- Assess real estate needs including ROW along highways, land use issues, local government planning and zoning conventions, and community mitigation needs.
- Identify the role of Texas, the level of support, and other actions that are needed to help coordinate, facilitate, and mitigate development of transfer hubs and rollout of automated trucking including resources for local governments. This may include identifying strategic lanes where TxDOT may want to incentivize AV truck service through investments in transfer hub infrastructure.

## *Assessing Texas Freight Network and Automated Truck Impacts*

Like the understanding of the siting of automated truck transfer hubs, automated trucking may impact the existing Texas Freight Network and local roadways. Due to past surface transportation laws, states are required to plan for freight, establish a State Freight Advisory Committee, and have an approved freight plan to use federal freight formula funding. Federal freight formula funding may only be used on the official freight network although states may use other funding sources anywhere, they wish. If a state were to use freight formula funding to support automated freight improvements including transfer hub development or information systems, the state would need to do so on the official freight network.

However, automated trucking entities describe network optimization and potential for more dynamic routes depending on things like congestion, work zones, demand, and other impacts. Automated trucking is expected to offer companies significant cost savings in the movement of freight. Algorithms to evaluate how automation can be used on optimized freight networks may offer a lucrative opportunity for companies. Using data from connected and automated trucks, companies can evaluate routes and quickly reroute or move freight differently to increase cost savings. Therefore, the freight routes and the level of activity on them may be dynamic. While the existing significant freight routes, especially the interstates, may not change as much, there might be changing dynamics related to first- and last-mile routes, as well as non-interstate roadways depending on mobility and reliability.

Currently, it is difficult to know how freight route optimization aligns with the way Texas has identified its freight network and how Texas operates and invests in it. It may be important to evaluate the existing network, assess it in relation to the expected optimization that automated trucking companies are describing, determine if the network might become more dynamic, and determine how to best plan for and operate the network in relation to how automated trucking will operate. For example, it is important to explore the following questions:

- How does autonomy change freight flows?
- What infrastructure changes should TxDOT consider in support of those changed freight flows?
- How should existing planning processes consider the potential impacts of autonomy?
- Where should TxDOT make strategic investments to guide those changes?

Specific activities to explore these questions include:

- Assess the existing freight network in relation to locations of automated trucking activity (i.e., routes and transfer hubs).
- Discuss and document how automated trucking network optimization might cause the routes to be dynamic and if there is an expected impact on the network or what other infrastructure support is needed.
- Understand where in the state circuits or specific freight routes are in order to prioritize locations for automated trucking implementation.
- Develop relationships to understand freight routing in detail and set up information flows between system operators and autonomous trucking companies to understand route plans and changes.

## *Developing a Freight CAV Ecosystem*

Given the existing and planned automated trucking activities and the saturation of the commercial market that is predicted, it is important to continue to cultivate a CAV ecosystem. While Texas' broader CAV efforts all contribute to developing this ecosystem in Texas, the state needs to continuously evaluate the needs of industry at different geographies (state level and local government) and functional class roadways.

Areas of focus in developing the ecosystem include the following:

- **Information repository:** TxDOT maintains an existing website with limited information on where automated trucking companies are operating, but in developing this document, researchers found a need for more information, details, and understanding from the companies operating in Texas. Additionally, companies operating in Texas may need information from the state such as details of freight infrastructure, freight flows, land uses, and other intel. A more interactive information repository might help to improve communication among the public and private sectors including awareness of who is doing what and where. Such a repository might help improve opportunities for testing by organizing information that industry may want to know when selecting sites. Figure 6 provides an example of this sort of repository. The figure shows an ArcGIS online application where users can see deployments, get specific information about them, and understand them in relation to other Texas information like the freight network, percentage of trucks on the road, freight infrastructure, land uses, and more. This might help industry in looking for location and testing opportunities and serve as a two-way platform for information sharing. Other platforms like Tableau or web-based sources would work as well. ArcGIS allows people to easily access the information to use as they need.

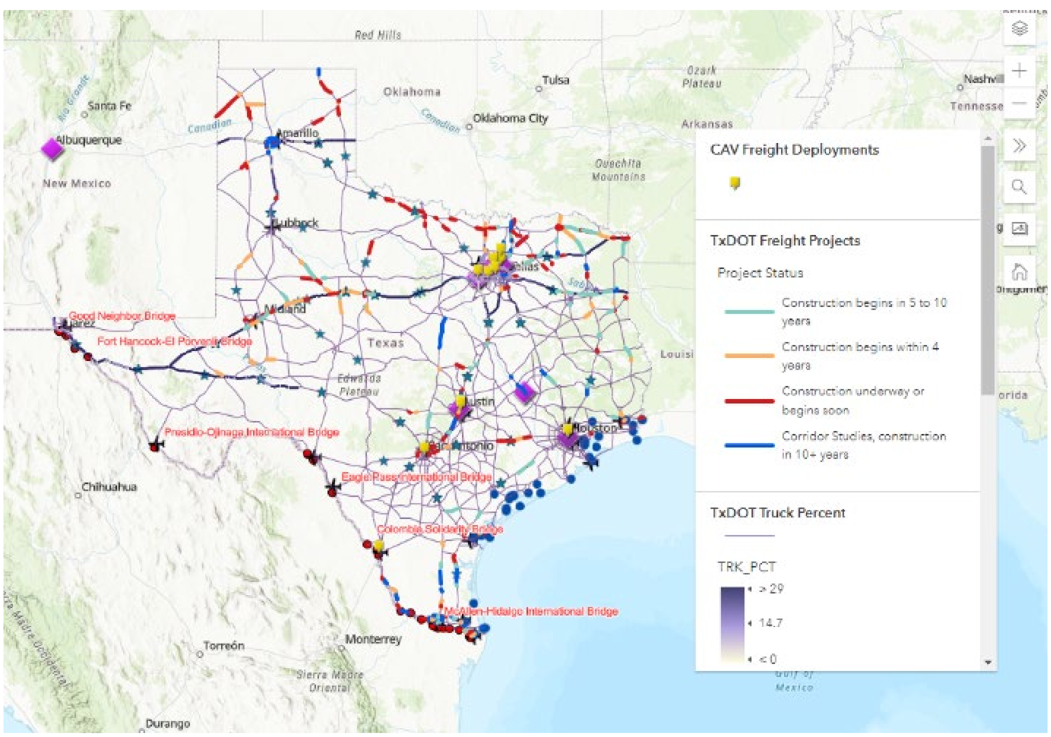


*Figure 4: Example of Information Repository for Freight CAV*

- **Data sharing:** In addition to an automated trucking repository to support planning and implementation, it is important that there be information-sharing components as projects progress. One example is the Work Zone Data Exchange in Texas, which enables infrastructure owners and operators to make harmonized work zone data available for third-party use, which helps make travel on public roads safer and more efficient through data on work zone activity. The goal is to get data on work zones in vehicles to help automated driving systems and human drivers navigate more safely (*1*). In addition, TxDOT has worked to improve data sharing in work zones to truckers on I-35. These types of data exchanges and prioritization of sharing information can help support automated trucking testing and implementation. Setting up data and information exchanges will ensure everyone has access to the information and that awareness is improved.
- **Assess and inventory:** Part of the information repository is to update or create available resources to keep track of freight flows, critical routes, performance, and commodities. TxDOT already has robust freight planning and tracking of freight fluidity (i.e., commodity type, tonnage, value, and bottlenecks), and this will help in supporting and conversing with freight CAV companies and industries as technology evolves. It will be useful for TxDOT to continue strong awareness of freight movement and to assess how networks will change when autonomous truck infrastructure is implemented. Additionally, different types of locations will attract different types of autonomous trucks or vehicles for freight movements. It is important to know the different types of freight networks supporting Texas industry (e.g., drayage and circuits) versus long-haul and regional routes to work with the private sector to support the types of infrastructure that will help these networks. Keeping up with freight information and then sharing it in a repository will help make sure the right information is available to develop a testing and implementation environment. Figure 7 depicts some of the rich freight commodity and performance flow information available at TxDOT to inform this effort.

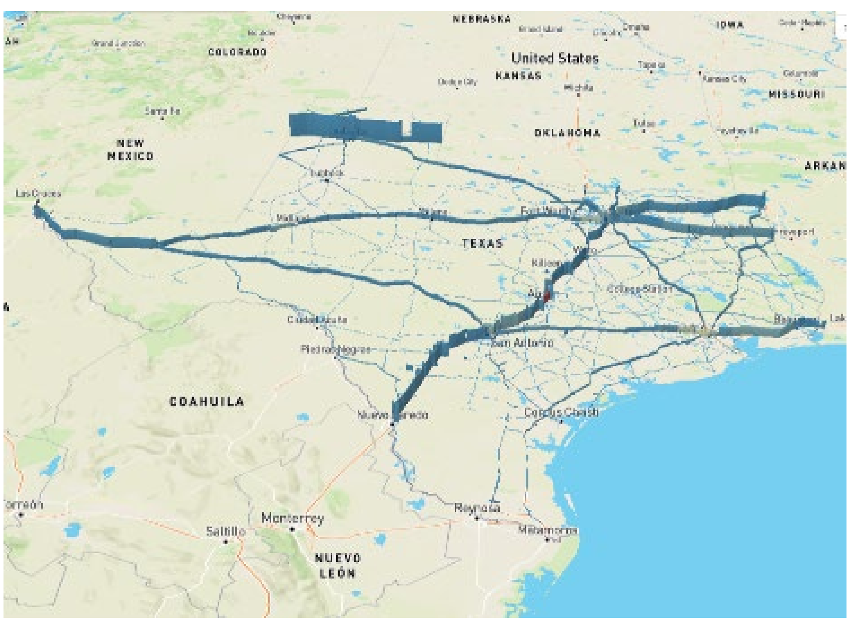


*Figure 5: TxDOT's Freight Fluidity Visualization Resource*

Additionally, it will help to have an inventory of property (state-owned or available) to support changing networks and needed highway ROW or transfer hub development. While property may be needed by the private sector, TxDOT can facilitate this by potentially offering property as well as helping with the community support needed for development of new infrastructure facilities. Property may be an important contribution or match in seeking federal transportation grants. The contribution of property may help support a private-sector investment, as well. This may be especially important in strategic corridors or freight-generating areas like borders, ports, and major facilities (e.g., Alliance Texas).

A good resource for this is existing truck probe data and the Texas Truck Parking Visualization Resource (Figure 8). It shows where truck parking demand is occurring statewide and provides usage statistics for truck parking locations throughout the state. This intel might be informative to industry partners in identifying areas to implement automation.

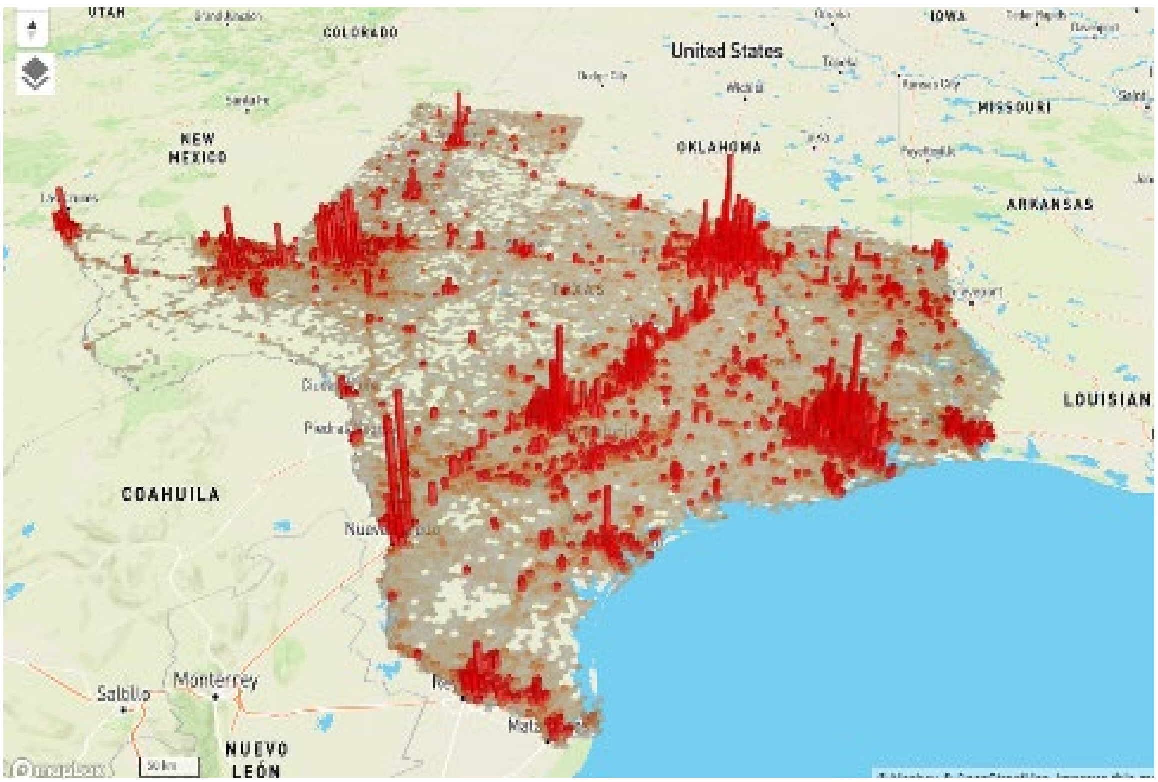


*Figure 6: Traditional Truck Parking Demand Statewide (Texas Truck Parking Visualization Resource)*

- **Get comfortable with data analytics**: TxDOT has sophisticated tools and resources available to support both planning and operations, and these will provide a strong foundation for the waves of data that can flow to and from autonomous trucks through V2X facilities. These data have the potential to provide significant intel for transportation operations that can illuminate in real time how trucks are experiencing Texas roadways. This kind of information can help with routing, treatments, and longer-term decisions such as where assets need attention. These data can also support TxDOT's ability to communicate with the driving community about safety, queuing, weather conditions, and more.

- **Develop public communications and outreach:** Though not an operational activity, public communications are critical for any transportation agency. A head start on identifying how autonomous trucking might impact communities may be critically important as 2024–2027 approaches and higher volumes of autonomous trucks are operating, in addition to the need to develop transfer hubs.
- **Remain flexible for future growth in operational changes:** As autonomous truck operations grow; operational changes will ensue. Operations centers will likely be located remotely, and communications with autonomous trucks will be conducted from afar. There may be a need for remote assistance. This may include full operation centers, where remote operators observe, operate, and interact with autonomous trucks. TxDOT operations staff will need to have a strong relationship and transparency with these centers so that staff can know what is moving and where and can safely operate the network, especially through V2X communications.

Therefore, specific action items for the immediate future may include:

- Setting up a data/information exchange and repository for more robust sharing of automated trucking activities and state information that can support industry;
- Taking inventory of assets, conditions, property, freight flows, and other important information to support the repository;
- Developing an effort to focus on CAV data, data exchanges, and V2X operations;
- Developing concepts of operation and identifying workforce needs, technology development, and other needs to support advanced data analytics and communications; and
- Focusing on an outreach and communications strategy that helps Texas citizens and local governments understand the changes that are occurring and brings them into the discussion on how transfer hubs are developing, what they can expect on freight routes, and other options to keep communications open that will help grow the ecosystem.

## Opportunities

The following summarizes the opportunities for advancing the three key categories of actions to support freight CAV activity in Texas.

### *Developing a Transfer Hub/Terminal Strategic Plan*

The following opportunities may help the state prepare for and support transfer hub development.

- Assess where there are potential terminal locations in relation to Texas' network and the use of existing tools to understand freight mobility in those areas.
- Assess future conditions to understand the impact of increased truck activity including a look at potential congestion, safety, and asset conditions.
- Develop a catalog of state-owned property and determine where potentially suitable transfer hub property exists that could support transfer hub activity.
- Develop a strategic plan focused on transfer hub development to include:
    - Understanding of existing plans by companies operating in Texas;
    - Evaluation of private versus open source and the potential impacts or issues;

- Understanding of freight flows and the freight network, as well as where it makes sense to have transfer hubs;
- Assessment of real estate needs including ROW along highways, land use issues, local government planning and zoning conventions, and community mitigation needs; and
- Identification of Texas' role, level of support, and other actions that are needed to help coordinate, facilitate, and mitigate development of transfer hubs and rollout of automated trucking including resources for local governments.

### *Assessing Texas Freight Network and Automated Truck Impacts*

The following opportunities can support an assessment of the transportation network, specifically the Texas Freight Network, to support automated trucking.

- Assess existing and future freight flows in the statewide freight plan and engage Texas industries concerning how they might be thinking of optimizing routes for autonomous trucking.
- Commit to maintaining and using resources (i.e., TCAT and newer freight fluidity tools released in 2023) to assess freight networks, tie commodities and industries to networks, and help identify points that might change or shift when autonomous trucks saturate the network.
- Evaluate truck flows at key freight locations to help identify drayage and circuit operations that may be best targeted for autonomous trucks or platooning.
- Identify potential drayage and circuit routes and what might need to be considered from an operational perspective that would support the freight movement while ensuring safety, efficiency, and environmental improvements.
- Have operations staff work with TxDOT planning, asset management, and pavement staff to research ways to offset asset decline or optimize asset performance given new, repetitive levels of activity on drayage and circuit segments.
- Assess the existing freight network in relation to locations of automated trucking activity (routes and transfer hubs).
- Discuss and document how automated trucking network optimization might cause the routes to be dynamic, and whether there is an expected impact on the network or other infrastructure support is needed.
- Understand where in Texas the circuits or specific freight routes are in order to prioritize for automated trucking implementation.

### *Working with District Offices to Understand Freight Routing and Build a CAV Ecosystem*

Multiple opportunities exist to develop a deeper understanding of the existing autonomous freight network in more detail, share information between the public sector and autonomous trucking companies, and advance a freight CAV ecosystem. These include:

- Continue development of  pilots and experiments with companies willing to share data, and test V2I data for state DOT decision-making purposes related to automated trucking. Identify what is useful, what kinds of intel it provides, and the best way to access and process the information. This should build on the TxDOT efforts described earlier, especially for areas like work zones.

- Review, update, and establish new operational procedures for inspections, incident management, routing, etc. that work with autonomous trucking as they do with conventional trucking. Consider how things might need to change, and what data feeds are needed and in what format for messaging the driving community.
- Establish a data/information exchange and repository for more robust sharing of automated trucking activities and state information that can support industry.
- Inventory assets, conditions, property, freight flows, and other important information to support the repository.
- Build on existing efforts such as the Connected Vehicle Data Framework to continue development of CAV data uses, data exchanges, and V2X operations, developing concepts of operation and identifying workforce needs, technology development, and other needs to support advanced data analytics and communications.
- Focus on an outreach and communications strategy that helps Texas citizens and local governments understand the changes that are occurring and brings stakeholders into the discussion on how transfer hubs are developing, what stakeholders can expect on freight routes, and other options to keep communications open that will help grow the ecosystem.

## Conclusion

The purpose of this paper is to present a framework for the next steps, actions, and coordination needed based on emerging freight CAV activity. The focus of this document is primarily strategies and updates for TxDOT and its partners to consider in planning and prioritizing actions to support emerging technology within the highway and controlled environment locations in Texas. Based on the expansion of the recommendations related to the current and planned emergence of automated trucking, Figure 9 illustrates the opportunities for TxDOT and its partners to support automated trucking in Texas.

The action items can be categorized into three categories:

- **Developing a transfer hub/terminal strategic plan:** developing an automated trucking transfer hub/terminal strategic plan that includes a thorough evaluation of existing and planned implementation in Texas, how this will impact the freight network, what the development impacts and needs are, and some specific outlining of roles and responsibilities, including support to local governments.
- **Assessing Texas freight network and automated truck impacts:** assessing how automated trucking will change the Texas Freight Network, what infrastructure is needed, what operations coordination would help, and where priority corridors or circuits are that support automated trucking.
- **Developing a freight CAV ecosystem:** creating an opportunity to share information between the public and private sectors in robust ways; offering ways for the private sector to input activities, and for the public sector to provide data about the freight network, freight facilities, existing freight flows, projects, and more.

These activities are possible to begin immediately and would likely take a year to collect and complete. However, in getting started and throughout the process, these activities would help TxDOT and its partners to organize information and additional actions in an optimized way and to strengthen (already strong) relationships with the private sector. This will help improve coordination, support, and success.

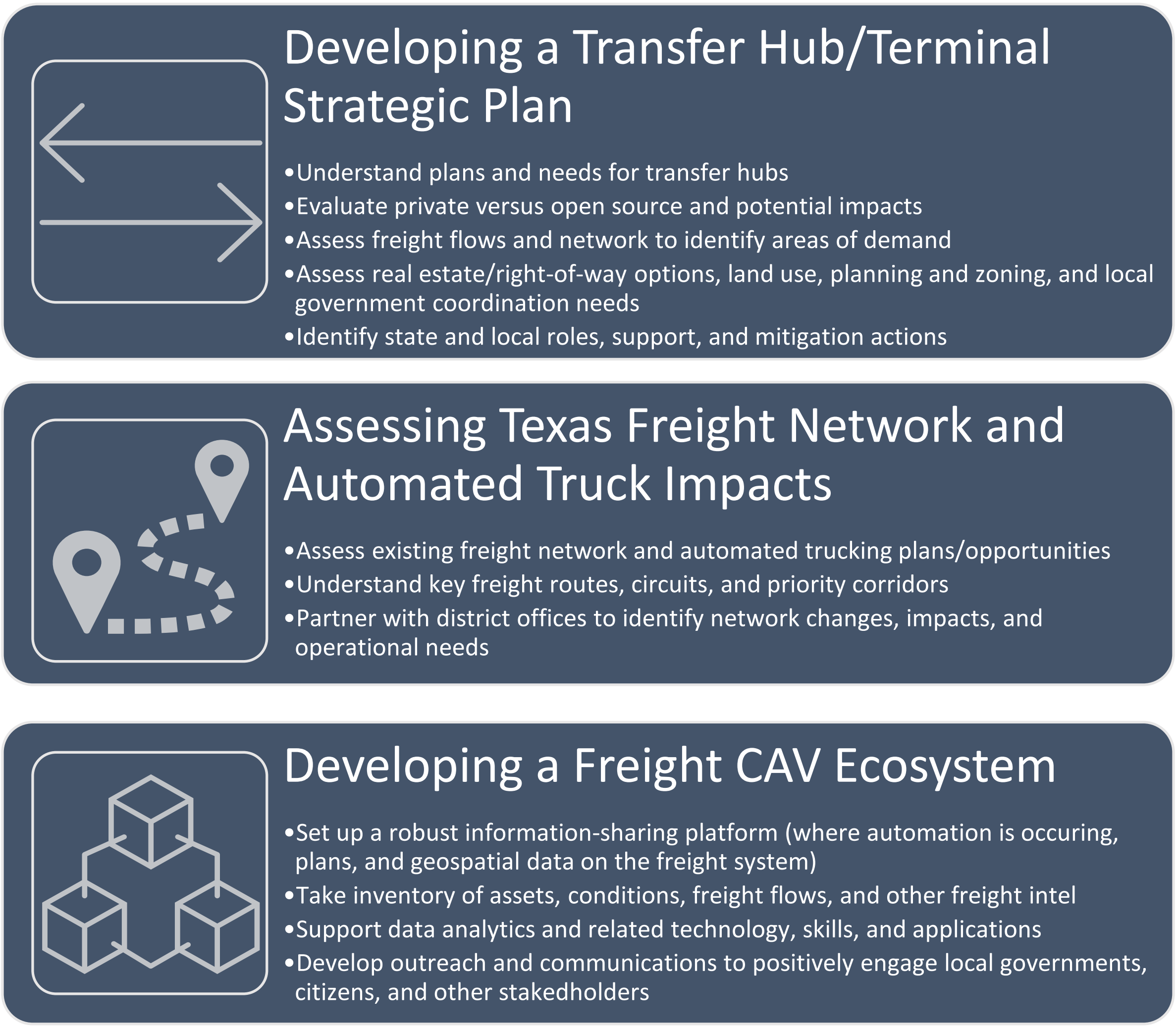


*Figure 7: Specific Near-Term Action Items to Support Automated Trucking*

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