Connected and Automated Vehicle (CAV) Hotspots

FINAL REPORT

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By: Kittelson & Associates, Inc. & HNTB Corp.

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16. Abstract

Technology is rapidly evolving, changing the way we travel and the trips we make. The Pennsylvania Department of Transportation (PennDOT) is preparing for these impacts by developing a methodology to assess the applicability of early Connected and Automated Vehicles (CAV) deployments ("CAV hotspots") within Pennsylvania. To ensure the CAV hotspots evaluation and methodology aligns with national guidance/research and the assumptions industry plans, the project team conducted a **literature review and national scan**. The project team documented **potential use cases** and identified where in Pennsylvania they may occur. Uses cases were a blend of connected and automated vehicle technology across different business models. The project team shared potential use cases with PennDOT stakeholders and selected the following use cases for evaluation: Automated Trucking; Personal Delivery Devices (PDD); Advanced Driver Assistance Systems (ADAS) for Personal-Use Passenger Vehicles; Vehicle-to-Infrastructure Transit; Infrastructure-to-Vehicle Information Systems.

For each of the selected use cases, the project team **identified and evaluated potential datasets** that could potentially be applicable. Then, the project team **developed a scoring methodology** and instruction sheet evaluating the likelihood of early market penetration of CAV technology given a specific use case. From the list of potential datasets, the project team selected a set of high-priority datasets to develop a scoring matrix that scores the likelihood of the technology to be deployed for the use case. The project team then **conducted the assessment** for two of the five use cases to generate a score for a specific region or corridor. Both locations scored reasonably high which indicated a reasonably high likelihood that the studied technology use case could be adopted in that location. For next steps, this tool is intended to be used by PennDOT, Districts, consultants, and local agencies to assess the applicability of other use cases in different regions and corridors in Pennsylvania.

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EXECUTIVE SUMMARY

Technology is rapidly evolving, changing the way we travel and the trips we make. The Pennsylvania Department of Transportation (PennDOT) is preparing for these impacts by developing a methodology to assess the applicability of early Connected and Automated Vehicles (CAV) deployments ("CAV hotspots") within Pennsylvania.

To ensure the CAV hotspots evaluation and methodology aligns with national guidance/research and the assumptions industry plans, the project team conducted a **literature review and national scan**. The scan documented:

- Completed and ongoing CAV Planning Activities
- Public opinion research
- Industry announcements on the deployment of CAV technologies
- Where pilots and operations are occurring in Pennsylvania and other states
- Key elements of Operational Domain Design (ODD) of vehicles, including speed and road classification

The literature review found several states have begun to develop technology transition plans or business plans for adapting to CAVs and partnering with private industry. The number of CAV deployments and pilots underway in Pennsylvania and around the world is also growing by the day. Use-case specific details including design environments, best practices, select pilots and deployment timeline, and public opinion research are documented in **Appendix A**.

Different use cases will have different impacts on initial deployments. The project team documented **potential use cases** and identified where in Pennsylvania they may occur. Uses cases were a blend of connected and automated vehicle technology across different business models. The project team shared potential use cases with PennDOT stakeholders and selected the following use cases for evaluation:

- Automated Trucking
- Personal Delivery Devices (PDD)
- Advanced Driver Assistance Systems (ADAS) for Personal-Use Passenger Vehicles
- Vehicle-to-Infrastructure Transit
- Infrastructure-to-Vehicle Information Systems

For each of the selected use cases, the project team **identified and evaluated potential datasets** (MS Excel data source matrix spreadsheet attached to this report) that could potentially be applicable. The datasets were selected from a variety of PennDOT-internal and external data sources, including both publicly available and restricted or private datasets.

The project team **developed a scoring methodology** (MS Excel scoring rubric worksheet attached to this report) and instruction sheet (**Appendix C**) evaluating the likelihood of early market penetration of CAV technology given a specific use case. From the list of potential datasets, the project team selected a set of high-priority datasets to develop a scoring matrix that scores the likelihood of the technology to be deployed for the use case. The project team then **conducted the assessment** for two of the five use cases to generate a score for a specific region or corridor.

To conduct the assessment, the project team worked with PennDOT to identify one region and one corridor for preliminary assessment of two different use cases. In each scenario, the project team applied the scoring methodology to compare the likelihood of the technology being deployed in that location.

- **Regions and Use Cases:** The region selected was Lehigh County for assessment of the ADAS methodology. The corridor selected was I-78/I-81 from the Maryland/Pennsylvania border to Allentown, PA for the assessment of the Infrastructure-to-Vehicle (I2V) use case.
- **Key Findings**: Both locations scored reasonably high which indicated a reasonably high likelihood that the studied technology use case could be adopted in that location. For detailed scoring, please refer to the Preliminary Assessment section of this report.

For next steps, this tool is intended to be used by PennDOT, Districts, consultants, and local agencies to assess the applicability of other use cases in different regions and corridors in Pennsylvania. The attached MS Excel rubric scoring worksheet, along with instructions in **Appendix C**, can be used to assess applicability of use cases in a variety of locations. In the future, the methodology described in this document and data sources spreadsheet matrix could be updated to reflect new data sources, use cases, or other developments with the technologies.

PROJECT OVERVIEW

This project was a study to determine the applicability of locations for early CAV deployments by developing a scoring methodology to help PennDOT prioritize CAV investments. The umbrella term "CAV" is often used to indicate varying levels of connectivity and automation.

The project team **conducted a literature review** of public agencies planning for and deploying CAVs and **identified potential uses cases** in Pennsylvania. The project team considered a blend of use cases consisting of connected, automated, and connected and automated vehicle technology to create a scoring system that PennDOT can use to compare locations to help prioritize CAV investments.

The project team then **identified and evaluated data sources** that could be applicable to the deployment of CAV and **developed a methodology** to evaluate the likelihood of early market penetration of a given CAV use case in a specific region or corridor. The purpose of this methodology is for agencies to prioritize investments in CAV technology by identifying which regions or corridors are best candidates for deployment. The intent of the tool is a way to prioritize among CAV technology investments and project locations. The tool does not address choosing between CAV technology and some other investment. The methodology may also identify locations that may not be areas for early deployment without support but could be with targeted investment in key areas or technical assistance from PennDOT. It may also serve as a self-scoring tool for grant applications, bolstering justification for funding requests for areas identified as ripe for early adoption.

The project team **conducted the methodology** for two use cases – I2V technology on the I-78/I-81 corridor and ADAS in Lehigh County – to generate a confidence score of the probability of deployment for that region or corridor.

LITERATURE REVIEW AND NATIONAL SCAN

This literature review and national scan includes research conducted by other jurisdictions and states as well as guidebooks published to provide agencies with best practices for incorporating emerging technologies. Please note this literature review was conducted in October 2021. It also includes national guidance and practices provided by organizations such as United States Department of Transportation, press releases and articles written by leading companies in the field, and research papers written by transportation professionals. This literature review and scan provides the necessary background to prior to describing the selected use cases and developing the methodology for predicting the likelihood of successful CAV deployments in varying regions of Pennsylvania.

It should be noted that CAV are developing both synergistically and separately. Throughout this document, vehicles will sometimes be referred to as CAV, Connected Vehicles (CV), or Automated Vehicles (AV).

- **Automated vehicles** can be almost any type of vehicle—for example, personal vehicles, trucks, buses, mobility scooters, delivery bots, or aerial drones—that has the potential to incorporate automation functions. Automation can provide all a vehicle's driver function or a driver-support role, where it assists a person in driving the vehicle, but the person must supervise the automated feature and perform other driving functions (Figure 1). For example, an adaptive cruise control system uses on-board sensors such as radar to detect the distance to the vehicle ahead.
- **Connected vehicles (CVs)** receive data sent by other vehicles, infrastructure, and/or services to assist a person with performing driving functions, such as navigation. CVs can also send data the other way, for example, to provide vehicle speed information that traffic managers and navigation services can use to monitor roadway conditions.
- **Connected and automated vehicles (CAVs)** use a combination of on-board maps and sensors, two-way communication, and software to perform most or all a vehicle's driving functions, to interact with nearby vehicles and infrastructure, and to provide status information to remote infrastructure and services.

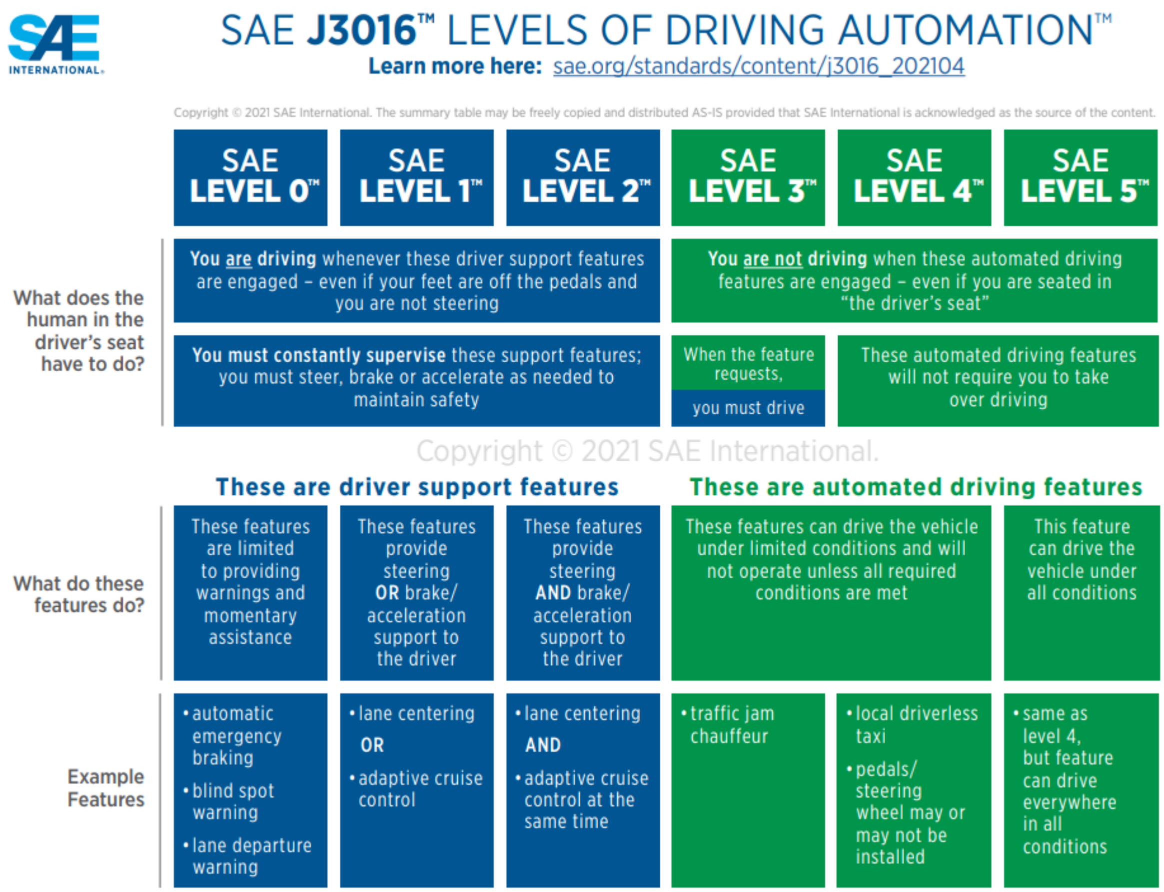

Figure 1. Five levels of automation (SAE International).

The literature review summarizes:

- A survey of completed and ongoing CAV planning activities and projects.
- Deployments of CAV operations in Pennsylvania and across the United States.
- A framework of ODD by speed and road classification.
- Use-case specific details including design environments, best practices, select pilots and deployment timeline, and public opinion research.

Appendix A provides details on best practices, timeline of implementation, and public opinion research for the five selected use cases. Please note the use cases described in **Appendix A** were further refined based on stakeholder input later in the project. All references for the literature review are also provided in **Appendix A**.

COMPLETED AND ONGOING ACTIVITIES

Several state agencies have begun to develop technology transition plans or business plans for adapting to CAVs. This section highlights the best practices of several states that have been early adopters of creating and implementing CAV strategic or business plans, conducting pilot programs, and partnering with private industry.

- PennDOT prepared the 2018 *Pennsylvania Joint Statewide Connected and Automated Vehicles Strategic Plan* to serve as a roadmap for organizational change as CAV technology advances.[1] The document addresses Pennsylvania's chief motivations, which include informing leadership of CAV developments about capabilities, limitations, projected timelines, benefits, and public safety; presenting findings from the Plan's development process; establishing the vision, mission, and goals of the Pennsylvania (PA) CAV Program; setting actionable steps for PennDOT; and outlining pilot projects to advance the PA CAV Program. The goals of the CAV strategic plan are to:
  - Improve safety
  - Enhance mobility
  - Prepare workforce
  - Foster and sustain partnerships
  - Increase public awareness of benefits and risks
  - Support economic competitiveness
- Florida is a leading state in testing CAV technology. There are many past, current, and planned CAV technology projects across the state, which are detailed on the Florida Department of Transportation (FDOT) Connected and Automated Vehicle Initiative webpage.[2] In 2015, FDOT established the AV/CV/ITS Steering Committee to coordinate and provide leadership direction over FDOT's statewide and regional initiatives. The committee was responsible for developing a strategic plan, drafting design standards for major infrastructure investments, initiating additional testing facilities, forming new non-traditional partnerships, and prioritizing investment locations. Since 2016, all state planning documents must consider the impacts of CAVs. In 2019, FDOT published the Florida CAV Business Plan. The Business Plan proposes seven key activities:
  - Identify policies and governance
  - Leverage program funding and identify other funding opportunities
  - Identify education and outreach program objectives
  - Develop industry outreach through active partnerships
  - Develop technical standards and specifications
  - Establish a platform for CAV implementation readiness
  - Move towards CAV deployment and implementation
- The Georgia Department of Transportation (GDOT) first prepared a Connected Vehicle Deployment Plan in 2016 to serve as a roadmap.[3] The initial 2016 plan specified a five-phase deployment approach, with the intent being that the deployment plan would be updated at the conclusion of each phase. As such, the 2016 plan has been expanded on with a supplemental Application Deployment Plan[4], and a Roadside Unit (RSU) Testing Summary.[5] The Plan was used as justification for the state's first pilot effort in 2017, which

[1] Pennsylvania Joint Statewide Connected and Automated Vehicles Strategic Plan

[2] Florida Department of Transportation (FDOT) Connected and Automated Vehicle Initiative

[3] Connected Vehicle Deployment Plan

[4] Concept of Operations, Application Deployment Plan

[5] RSU Testing Summary

was pursued in response to the American Association of State Highway and Transportation Offices (AASHTO) Signal Phase and Timing (SPaT) Challenge. The intent of the original 2017 CV pilot deployment was to establish Vehicle-to-Infrastructure (V2I) communications and was a traffic signal-based application demonstration focused at 54 intersections.

- In 2016, Massachusetts Department of Transportation (MassDOT) was designated by Governor Charlie Baker as the lead agency in authorizing testing of Advanced Driving Systems (ADS)-equipped vehicles on public roadways. The Governor signed Executive Order (EO) 572, which established an Autonomous Vehicle Working Group.[6] The AV Working Group, with agency members at MassDOT and the City of Boston, created an approval and licensing process for AV testing in the state as their first action. This led to two Massachusetts-based companies, nuTonomy/Motional and Optimus Ride, being permitted to conduct ADS tests since December 2016 and May 2017, respectively.
- In late 2015, Maryland Department of Transportation (MDOT) Secretary Pete Rahn established the Autonomous and Connected Vehicle Working Group with the aim of developing and deploying emerging CAV technologies in Maryland. The group evaluates the latest research, tracks federal and state laws, policies and programs, and coordinates with other agencies, organizations, and businesses to set the course for the future of CAVs in Maryland. Maryland Transportation Authority (MDTA) is actively involved in this group and has developed a strategic plan for CAVs.[7] The Strategic plan proposes 4 major actions including:
  - Build and maintain strategic partnerships.
  - Develop and conduct CAV pilot projects.
  - Determine infrastructure-related design standards for CAV.
  - Explore the revenue-generating potential of CAV technology use on MDTA facilities.

Based on the best practices of the above states that have navigated CAV-related planning, adopted CAV strategic plans, and conducted CAV pilot projects, common key takeaways, and best practices for identifying CAV deployment locations include:

- Identifying environments that foster innovation. The use cases under consideration for the PennDOT Hotspots project are those being used by the general public, transit agencies (e.g., transit signal priority), or private industry (e.g., automated trucking applications). Therefore, in selecting deployment locations, it is critical that the general public or end users of the applications are comfortable with the use case deployment environment given current capabilities of the technology. It is also important these locations have an identified problem that could be addressed with use of the technology.
- Understand plausible deployment scenarios and locations, their implications, and risks to transportation systems through scenario planning and exploratory modelling.
- Assess roadway readiness by considering factors such as infrastructure readiness and uniformity of roadway markings, signage, quality of pavement conditions, etc. Develop a scoring matrix for these factors to prioritize investments and technology deployment locations.

[6] Executive Order 572

[7] Maryland Transportation Authority Strategic Plan for Connected and Automated Vehicles (CAV Plan)

PILOT ACTIVITIES

Note: This literature review focuses on PA-specific example. For other projects around the country and world that PennDOT could learn from, please reference the FHWA's Interactive Deployment Map or the 2016 International Scan of Connected and Automated Vehicle Technology Deployment Efforts from the Michigan Department of Transportation and Center for Automotive Research.

Pennsylvania is home to several automated and connected vehicle companies, pilot projects, and potentially the PennSTART CAV testing facility (in development phase). The Pittsburgh Strip District is now home to "Robotics Row", exploding with technology, robotics, and autonomous vehicle industry players. Highlights of Pennsylvania CAV pilot and testing efforts include:

- PennDOT received over $8M in grant funding from the USDOT's Automated Driving System program to demonstrate Safe Integration of AVs in Work Zones.
- In 2018, Act 117 was passed allowing platoons of up to three vehicles to operate on public highways. Locomation just completed a year of testing of their "Autonomous Relay Convoys," two-truck convoys with a lead truck and a follower truck and two drivers, on interstate highways in early 2021.
- The Smart Belt Coalition (SBC), a tri-state collaboration between transportation agencies and educational institutions in Michigan, Ohio, and Pennsylvania, issued a Request for Information regarding details and a demonstration of "Truck Automation and Platooning" technology in early 2020 and continues to research these technologies on a multi-state corridor basis. The SBC conducted an automated truck platooning demonstration that ran from Pittsburgh to Detroit, Michigan in October of 2020.
- As of March 7, 2022, PA has eight companies registered as automated vehicle authorized testers, operating on public roads in counties across the Commonwealth. Notably Argo AI, Aurora Innovation, Uber ATG (acquired by Aurora in 2020) and Motional are all performing on-road testing around Pittsburgh.
- The Philadelphia Navy Yard development includes a multi-route pilot project to use driverless shuttles to introduce new transit routes for sporting events and office worker access to amenities. The shuttle is envisioned to operate at speeds commiserate with human-driven vehicles along roadways with posted speed limits of 35 mph. This service will launch in Summer 2022.
- In September 2021, the City of Pittsburgh began Phase 1 operation with Kiwibot to deliver books, medicine, and food to residents of select neighborhoods. Kiwibot was authorized for operations in June 2021.

USDOT hosts an interactive map that captures many of the Connected Vehicle Deployments across the United States.[8,9] Additionally, the National Highway Traffic Safety Administration (NHTSA) hosts a test tracking tool that shares information about AV test sites, vendors, and state by state information.[10] The examples provided in this literature review are PA-specific, but the CV and AV deployment maps provide resources for other projects happening around the country that PennDOT could learn from. Providing information to the USDOT for these databases is voluntary, so they do not capture every possible effort. Current activities in PA captured in USDOT's interactive CV Deployment map include:

- Pennsylvania Turnpike Harrisburg Connected Corridor

[8] Connected Vehicle Pilot Deployment Program

[9] Interactive Connected Vehicle Deployment Map

[10] AV Test Initiative

- Signal Phase and Timing Deployments and Test Beds
  - Pennsylvania DOT Harrisburg Demonstration
  - Pennsylvania DOT Ross Township Test Bed
  - Philadelphia SPaT
- Smart Belt Coalition
- SmartPGH
- PA Automated Driving System Grant
- Penn DOT I-76 Multi-modal Corridor Management Project
- Penn Turnpike Harrisburg Connected Corridor

Many vehicle manufacturers and automated driving system developers are planning to expand their on-road testing and pilot programs in the immediate future. As such there is an ever-growing playing field of vendors that often have more plans than are publicly available. The number of CAV pilot projects continues to increase in Pennsylvania and nationwide. The technologies are complex and require strong partnerships between public agencies and technology companies. The state of the technology remains in its infancy – mainly confined to pilots, as opposed to fully operational deployments, in very controlled environments, often with human operators. Only some of the existing CAV technologies such as ADAS are available for public purchase and fully automated vehicle are not yet available for the general public.

OPERATIONAL DESIGN DOMAIN

The operational design domain (ODD) defines the conditions in which a CAV can operate safely. NHTSA has defined several attributes of the ODD, including:

- Physical infrastructure (roadway types, surfaces, edges, and geometry)
- Operational constraints (speed limit and traffic conditions)
- Objects (signage, roadway users, and non-roadway user objects/obstacles)
- Connectivity (vehicle, traffic information, remote fleet management system, infrastructure sensors)
- Environmental conditions (weather, roadway conditions, particulate matter, illumination)
- Zones (geo-fencing, traffic management zones, school/construction zones, and regions/states)

ODD can be looked at from different perspectives. Most important for this study is to understand what is important to assess CAV readiness. When considering where private companies will choose to deploy fleets of CAVs, infrastructure readiness is a key consideration and something that agencies like PennDOT have at least partial control of influencing through a combination of investment, policy, and awareness. This study focused on physical infrastructure because it's a component of the ODD that PennDOT has an opportunity to influence.

The National Cooperative Highway Research Program (NCHRP) 20-24(112) *Connected Roadway Classification System (CRCS)* project developed a framework that can be used to classify infrastructure readiness for CAV deployments.[11] To prepare infrastructure for CAVs, the study identified four broad approaches that PennDOT has

[11] Connected Roadway Classification System Development

at least partial control of (Figure 2).

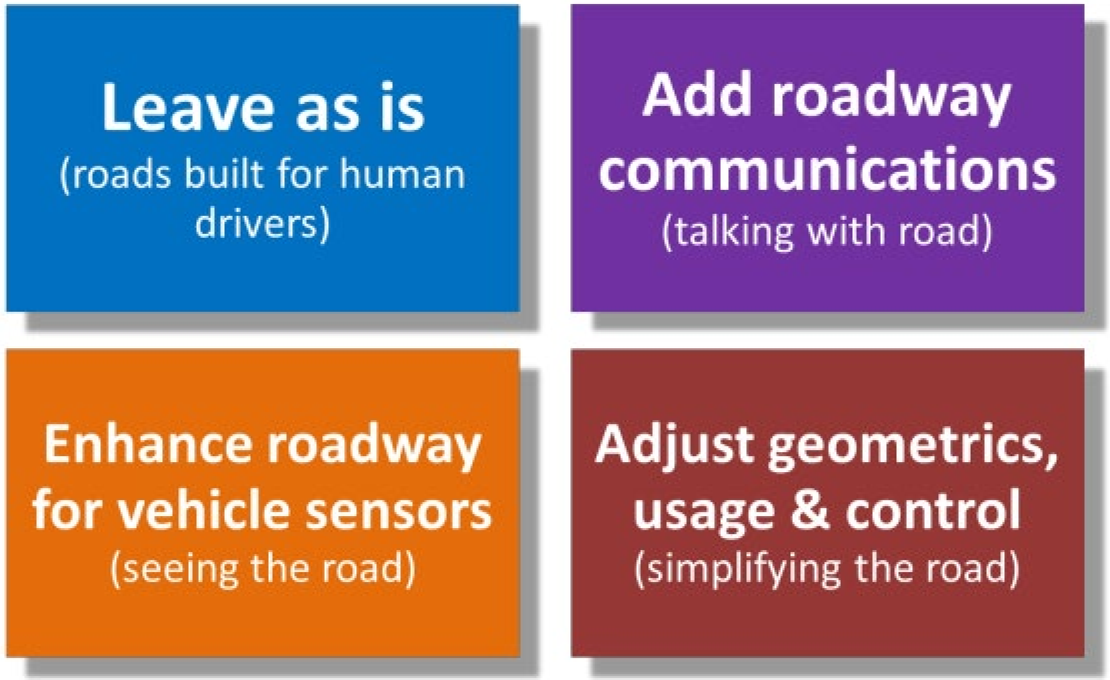

Figure 2. CAV Infrastructure Approaches (NCHRP 20-24 (112))

For this study, each technology use case will have a specific ODD. In narrowing down the choices to evaluate further, the amount of influence that PennDOT has on the design environment was considered. ODDs vary by CAV use case. In terms the physical infrastructure component of the ODD, it can be summarized in the following four roadway type deployment environments:

- Sidewalk and off-road
- Dedicated lane
- Shared road use (collectors and arterial roads)
- Shared road use (highways and interstates)

Appendix A provides examples for each of these ODD groups and details the design environments for the five selected use cases in this CAV hotspots study.

IDENTIFY USE CASES

Three focus groups were held between June 28 – 30, 2021 with District Traffic Engineers, Central Office staff, and staff of local municipalities and regional planning organizations (further referenced as local agencies). The purpose of the focus groups was to understand which emerging technology use cases were currently impacting their work or would impact their work in the future.

Four broad takeaways came from the focus group sessions related to identifying and prioritizing use cases:

- Distinguish between technologies for use by PennDOT and those for use by the public.
- Account for technical readiness of technologies. Some technologies will depend on the readiness of the geographic region, while others will launch with minimal need for help from PennDOT or local agencies.
- Consider how company targets (which vary by technology and company) influence the likelihood of a deployment successfully launching in a certain location.
- Engage with local staff who have performed the most planning and remain the most skeptical.

POLL

Eight sample use cases were described and discussed with each focus group:

- Passenger Vehicles with Vehicle-to-Infrastructure Connectivity
- Connected & Automated Vehicles for Personal Use
- Connected Transit Vehicles
- Commercial Vehicle Platooning or Highway Automation
- Automated Full-Size Transit Vehicles
- Personal Delivery Devices
- Automated Ride Hailing
- Low-Speed Automated Shuttles (LSAS)

Following the description of each use case, participants were asked to rank each use case based on the participant's "perception of the influence of each in your future work." **Appendix B** provides the results of the poll.

Combined poll results indicated high prioritization of passenger vehicles with V2I infrastructure connectivity and CAV personal use, with low prioritization of automated ride hailing and LSAS. This trend was consistent across local, District, and Central Office levels. As shown in **Appendix B**, District results indicated a much higher prioritization for passenger vehicles with V2I connectivity than local agencies or Central Office, but CAV personal use was ranked consistently by all stakeholders. Central Office and local agencies held differing values for the rest of the use cases. Central Office valued connected transit, platooning commercial vehicles, and full-size automated transit vehicles more. Local agencies valued personal delivery devices, LSAS, and automated ride-hailing more. District rankings aligned well with Central Office rankings outside of passenger vehicles with V2I connectivity and full-size automated transit vehicles.

Following the poll, participants were asked open ended questions, including additional use cases and experiences with polled use cases, important considerations from a planning perspective, concern and interest for use cases, and data sources for targeting use case infrastructure needs. The summary of the questions is detailed in **Appendix B**.

RECOMMENDATION OF FIVE USE CASES

Following the focus groups, the CAV Hotspots project team met to discuss the findings of the focus groups and to recommend which five use cases to advance for further methodology development to identify hotspots where the use case is most likely to deploy long-term as a proven technology (i.e., the use case has already completed successful pilots). The use case hotspots methodology took as inputs the use case and a region or corridor (as appropriate for the use case), to then provide as an output the likelihood that the region or corridor will be an early adopter of the use case in the Commonwealth of Pennsylvania.

USE CASE SELECTION PROCESS

The CAV Hotspots project team used the following process to select the five use cases:

1. **Comprehensive list of use cases.** The CAV Hotspots project team considered the eight use cases presented to the focus groups, as well as additional use cases of interest identified by the stakeholders. Some use cases were divided to distinguish between technologies that will be driven by public agency investment or private industry development. For example, connected transit vehicles was separated into V2I transit vehicles and I2V transit vehicles. From the perspective of a public agency:
    - **V2I** communication involves vehicles sending information to roadway infrastructure that public agencies may control.
    - **I2V** communication pushes data out to vehicles in the opposite direction—from infrastructure public agencies may control to travelers.
    - **Vehicle-to-Everything (V2X)** is two-way data sharing between vehicles, transportation infrastructure, and other road users. This use case is the most robust technology, but until this use case is widely available, public agency control is somewhat limited to the infrastructure communications component.
2. **Evaluation metrics.** The project team met with PennDOT's Office of Transformational Technology to better understand the purpose and use of the methodologies. The project team then developed a set of evaluation metrics for evaluation of the use cases.
3. **Scoring.** Each project team member independently scored each use case across each metric using literature and prior knowledge of the use case. The project team then met to compare and discuss scores, agreeing on a common value.
4. **Evaluation, Results, and Recommendations.** The average score of all metrics was calculated. The project team reviewed these scores and selected two connected use cases and three automated use cases for recommendation. In some cases, similar use cases were combined as noted in the I2V Information System use case.

The initial list of use cases considered included:

- Platooning Freight
- Low-Speed Automated Shuttles
- Advanced Driver Assistance Systems (SAE Level 2 Automation) on Personal Use Vehicles

- Automated Vehicles (SAE Level 4 Automation) for Personal Use
- Automated Transit
- Automated Trucking
- Personal Delivery Devices
- Automated Ride Hailing
- I2V Signal Phase and Timing Messaging
- I2V Information Systems [including Road Weather Information System (RWIS) and Traveler Information]
- I2V for Pedestrians, Cyclists, and Micromobility
- I2V Safety applications
- V2I Freight
- V2I Passenger Vehicles
- V2I Transit
- V2I Pedestrians, Cyclists, and Micromobility
- Advanced Traffic Management Systems (ATMS)
- Parking Management Systems (PMS)

The list of evaluation metrics included:

- Market Deployment Timeline
  - Selections were based on relative release dates of market deployments, not pilots. Use cases close to deployment ranked higher than use cases with later expected market deployments.
- Need for Agency Resource Investment
  - Selections were focused on the use case's overall need for resource investment by public agencies. Use cases that require more public agency resources ranked higher than those that are mainly reliant on private resource investment.
- Potential PennDOT Impact
  - Parties responsible for bringing the use case to market were considered. Use cases that PennDOT has the authority to accelerate were prioritized, followed by use cases where PennDOT's role would be more limited to assisting other agencies with design standards or policy recommendations.
- Data Available for Methodology
  - Use Cases with data available for a public agency to use to evaluate the effectiveness of a deployment were ranked higher than those without available data. Evaluation data are summarized in the next section of this report. This ranking is largely based on preliminary judgement by the project team and was further refined explored in Identify and Select Data Sources section.
- CAV Strategic Plan Alignment
  - Preference was given to use cases aligned with the Pennsylvania Joint Statewide Connected and Automated Vehicles Strategic Plan. Use cases that had less alignment with the Strategic Plan ranked lower in this category.

Scoring results can be found in **Appendix B**. Where ties existed, priority was given to use cases that had a higher potential for PennDOT impact – meaning PennDOT has at least partial control of influencing support the technology through a combination of investment, policy, and awareness This was important in the ranking of Level 2 Personal Use, Automated Freight, Personal Delivery Devices, Automated Transit, and Platooning Freight.

The following use cases were ranked high but were excluded from the recommendation to advance to methodology development:

- Low-Speed Automated Shuttles
- Automated Vehicles (SAE Level 4 Automation) for Personal Use
- ATMS

Low-Speed Automated Shuttles. This use case ranked low among stakeholders in the focus groups. These vehicles are being pilot tested across the country and world, including in Philadelphia's Navy Yard. Federal safety standards are being considered for the automated driving systems, but it will take years before system performance requirements are finalized and effective. Currently, the low-speed of these vehicles requires them to operate on low-speed, low-volume roads, which are more likely to be local roads, rather than PennDOT-controlled state roads. The vehicles are also limited by NHTSA where they can operation as they do not meet many NHTSA Federal Motor Vehicle Safety Standards (FMVSS). PennDOT can support local agencies interested in deploying these shuttles through grant applications, route planning, and operations monitoring. This use case was not prioritized despite the high scoring because PennDOT is not the agency responsible for the procurement, maintenance, or operations of this use case. Transit agencies will be the primary operator of these vehicles.

Fully Automated Vehicles for Personal Use. This use case scored high because extensive agency investment will be needed to support the safe and efficient performance of these vehicles at either high speeds or in mixed traffic. However, the private industry controls the selection of operational design domains that these systems are designed to work in. Given the unknowns in deployment timeline and feasibility, this use case was not prioritized for methodology development.

ATMS. This use case will benefit from future connected vehicle data sharing. This use case ranked high because the systems using connected vehicles are in the pilot testing phase. Traffic system data is available for system performance evaluations, and agency investment is required to accelerate system deployment. However, this use case was not recommended because local agencies control the traffic signal systems and because the timeline for widespread connected vehicle deployment is driven by the private industry.

RECOMMENDED USE CASES

The five recommended use cases for methodology development are:

- Automated:
  - Advanced Driver Assistance Systems (SAE Level 2 Automation) for Personal Use Passenger Vehicles
  - Automated Trucking
  - Personal Delivery Devices
- Connected:
  - I2V Information Systems
  - V2I Transit

Advanced Driver Assistance Systems (SAE Level 2 Automation) for Personal Use Passenger Vehicles. Partial automation is achieved by SAE Level 2 driver assistance systems, which are currently available and even becoming standard equipment on a growing number of light vehicles. The potential safety and mobility benefits of SAE Level 2 Automation highly aligns with the Pennsylvania CAV Strategic Plan. Systems like lane departure warning or roadway departure warning could be usable in more areas with better pavement marking, and PennDOT maintains most of the highway miles that these systems would be active on. As such, PennDOT will need to make decisions about improving markings on various corridors. Additionally, PennDOT could enter into a partnership with original equipment manufacturers to use some of the ADAS data (hard braking, automatic emergency braking activations, etc.) to identify potential safety problems.

Traffic jam assist and speed limit warning systems could be enhanced with I2V messaging or enhanced signage, which may be the responsibility of local agencies or PennDOT. While traffic jam assist and speed limit warning systems could be enhanced by connectivity, they are still operational today. Improvements to connectivity will enhance the use case but the use case is not dependent on it to operate.

Limited data is publicly available about the performance of these systems, but research partnerships are successfully establishing data sharing agreements to use the vehicle data to monitor system performance (like the Purdue University research using Wejo data to monitor hard braking events). [12] The methodology will evaluate this use case in the urban/rural region context.

Due to the variety of ADAS technologies currently available, the methodology for ADAS was broken into two components to match specific ADAS technology solutions with the identified problems and roadway characteristics in a region. The lateral applications component evaluates the potential of roadways to support lateral ADAS technologies, such as lane keeping assist and lane departure warning. The longitudinal component evaluates roadways for their potential to support longitudinal ADAS applications, such as traffic jam assist or forward collision warning.

Automated Trucking. The comparatively shorter market deployment timeline compared to other automation use cases, high availability of data for methodology, and strong alignment with the Pennsylvania CAV Strategic Plan were primary factors that led to the prioritization of automated trucking. The freight industry has had a heavy focus on platooning in the past, where one company uses V2V technology to communicate from a lead vehicle to a following vehicle. The closed nature of the system, with all vehicles being from the same fleet, means companies can implement the connected vehicle infrastructure without regard for the communication system used by other operators or infrastructure owners. As time progresses, industry has shifted away from platooning to full automation. This will require more reliance on the action of public agencies. Performance of full automation will need to be supported through enhanced signage or striping. PennDOT is the public agency primarily responsible for investing in these improvements on limited-access highways. Therefore, this use case is identified as a high priority. The methodology will evaluate this use case in the highway corridor context.

Personal Delivery Devices. This use case did not rank as high in PennDOT impact because private industry is driving the technology deployment and development – this service is expected to be deployed on local roads, and evaluation data is not yet available. However, PennDOT can play a vital role in supporting local agencies to plan, monitor, and enforce the emerging applications of automated delivery vehicles. Local agencies may need support with roadway design guidance to provide access from the roadway or sidewalk network to the delivery destination. Local agencies may need guidance establishing sharing agreements with deployment vendors so that agencies can monitor the performance and impacts of these systems. Additionally, local agencies may need guidance on how to report and enforce violations, crashes, or conflicts between these vehicles and other

[12] Hard Breaking Event Dataset for I-35, TX

pedestrians or bicyclists on the sidewalks. This use case is recommended for methodology advancement because of the guidance that PennDOT can provide to support local agencies. The methodology will evaluate this use case in the regional context.

I2V Information Systems. PennDOT is in a strong position to accelerate I2V connected vehicle applications of traveler information systems, such as Road Weather Information Systems and 511 travel information messaging. These systems are being pilot tested in the USDOT Connected Vehicle Pilot Deployment Program in Wyoming. Applications could be expanded to include real-time truck parking availability information. Public agency investment is needed to accelerate the technology deployment, and PennDOT is the primary agency to lead this investment. The methodology will evaluate this use case in the highway corridor context.

V2I Transit. Transit vehicles are the strongest example of connected vehicles in sustainable deployment. Transit signal priority (TSP) systems are functional V2I systems that have been successfully deployed across the country. This use case scored high because data are available for performance evaluations, and methodologies are established. Additionally, these systems require public agency investment in vehicle equipment, traffic signal controllers, communications equipment, and signal control systems. However, transit agencies determine the vehicle equipment investments and local agencies control and maintain the traffic signal systems in Pennsylvania. PennDOT can support local agencies interested in advancing connected transit through facilitating inter-agency coordination between local traffic signal operators and local transit agencies, providing guidance on system planning and operations, and support grant applications for funding. The V2I transit use case is recommended because PennDOT has available data that can be used for the hotspots methodology. The methodology will evaluate this use case in the urban/suburban corridor context.

IDENTIFY AND EVALUATE DATA SOURCES

The project team identified and evaluated data sources (Data Sources Matrix) that could be applicable to the deployment of CAVs and to predicting the likeliness to deploy.

Attached to the report is a MS Excel matrix of data elements which details how each source could be applicable to the previously identified use cases:

- Advanced Driver Assistance Systems for Personal Use Passenger Vehicles
- Automated Trucking
- Personal Delivery Devices
- Infrastructure-to-Vehicle Information Systems
- Vehicle-to-Infrastructure Transit

The purpose of the evaluation was to identify those datasets which could be used in development of the CAV Hotspots Methodology (See Methodology Section). The methodology evaluates the likelihood of early market penetration of a given use case in a specific region or corridor.

The project team evaluated 261 datasets from a variety of PennDOT-internal and external data sources, including both publicly available and restricted or private datasets. Each of the datasets was evaluated for granularity, spatial coverage within Pennsylvania, and ownership of the data. Then, the project team categorized those datasets which could be useful in the development of at least one of the five use case hotspot methodologies.

The attached matrix provides information about the main list of datasets selected from the 261 total for potential applicability to one or more use cases, including name, source, ownership, granularity, spatial coverage, and any other pertinent notes. It was not expected that every dataset listed in the matrix would be used; however, the project team considered this the full list of datasets which may be used. The intent was to identify all potential data sources that might be useful. The MS Excel dataset matrix attached to the submission of this report lists the selected datasets and sources for each use case. The matrix notes where temporal constraints may limit the data applicability. The category generally refers to the location within the PennDOT or Department of Community & Economic Development (DCED) map system where the dataset is stored

SELECTED DATA SOURCES

After the project team identified all potential data sources and evaluated each source's applicability to one or more of the selected use cases, the project team conducted an additional refinement of data sources. The final selection of data sources identified high-priority data sources for each case; in other words, key variables or data points that were critical in the development of a methodology to determine a likelihood of a particular use case deployment in a specific region or corridor. As part of this task, the project team developed a finalized list of applicable data sources (factors) for use in the methodology, identified specific data points or layers within each dataset. The selected set of variables and associated data sources were used to develop a methodology worksheet for each use case. The variables and associated datasets are detailed in **Appendix C** instructions for conducting the assessment and the attached MS Excel assessment worksheet.

METHODOLOGY

Using the selected datasets, the project team developed:

- A rubric for scoring each factor (attached MS Excel spreadsheet),
- A worksheet to compile the rubric scoring for each use case (CAV Hotspots Rubric Instructions (Appendix C))

Along with the scoring worksheets for each use case, an instruction sheet (**Appendix C**) provides the following information:

- A scoring description and overview of the use case,
- Step-by-step instructions for completing the worksheet, including how to select the region or corridor, and
- Considerations for interpreting the final score.

The instruction sheet directs analysts to applicable data sources for use in the methodology. In some cases, the project team identified potential limitations of existing datasets or other datasets that could be applicable in future iterations of this methodology.

- For Personal Delivery Devices, datasets with sidewalk quality and width could be applied to future assessments if the data were available.
- For use cases including pavement markings as a scoring variable, there is no statewide pavement marking asset management system and therefore no uniform way this data is recorded. Each District independently tracks when a pavement marking is applied or renewed using their own system.
- For Department of Community and Economic Development datasets, such as Freight Industry locations, it is unclear if the locations in the dataset are warehouses that may be applicable to the automated trucking use case, or if they are corporate office locations. This data should be supplemented with local knowledge for highest accuracy.
- For Multi-modal Project Management System (MPMS) projects in the PennDOT One Map system, an additional improvement type filter of "ITS" would be helpful for the I2V use case. This would allow for the ability to enhance planned ITS projects with I2V technology as appropriate.
- For automated trucking, the project team vetted the methodology and variables with private industry representatives. The current methodology includes weather variables (persistent snow and fog) as potential barriers to early deployment. Industry representatives expressed a need for future deployments to be able to handle non-recurrent fog and snow or to adjust deployment models to work around adverse weather conditions. Future iterations of this methodology after initial deployments have launched may consider downplaying or removing the impact of weather variables. However, for this methodology of identifying first launch areas, persistent snow and fog could be a barrier to early deployment. Industry confirmed other variables, including a desire to integrate as closely as possible into existing supply chains and locations, rather than creating new trucking areas.
- Future iterations of this methodology may include considerations for long-term work zone locations. Work zone locations can pose challenges for fully automated vehicles, including trucks.
- For Advanced Driver Assistance Systems, the National Household Travel Survey vehicle age dataset is only available for Metropolitan Statistical Areas (MSA) of more than 1 million people. There are three MSAs of more than 1 million people in Pennsylvania. Vehicle age for all MSAs less than 1M population (across the

US) was used as a default value for all areas outside of the 3 MSAs. This will likely result in bi-modal scores with Philadelphia, Pittsburgh, and the small portion east of Scranton scoring similarly while the rest of the Commonwealth would score worse. In the future, vehicle age data from the Department of Motor Vehicles may provide more granular vehicle age analysis for evaluation at the region or county level. It would also improve the ability to have specific data for MSAs in Pennsylvania which have fewer than 1 million people.

- In addition, please note the limitations of vehicle age as a variable to determine where ADAS may be utilized most. Advanced Driver Assistance Systems are currently deployed on some vehicles throughout the Commonwealth of Pennsylvania. However, there are no federal requirements for the technology to be installed on all new vehicles or standards on the performance requirements or applications. If ADAS is installed on a vehicle, the driver may also have the system disengaged. Given these challenges we originally did not develop the methodology to identify on which roads vehicles are equipped with Lane Keep Assist (LKA) or Lane Departure Warning (LDW) and drivers have the systems enabled. Instead, we focused on identifying roadway characteristics that PennDOT can control to enable better performance of ADAS. The thought behind this is that if PennDOT can focus on infrastructure improvements making LKA/LDW more likely to engage (for example, due to reliable pavement markings), drivers with LKA/LDW installed will be more likely to engage the system. Since there are many roadways where pavement markings can be improved, we focused on variables that suggested the roadway had run-off-the-road or head on collision concerns, meaning any pavement marking improvements would benefit all users, even those without LKA/LDW equipped vehicles.

PRELIMINARY ASSESSMENT

This section provides the results of a preliminary analysis of two use cases – ADAS and I2V Information Systems. Attached to this report are completed rubric worksheets for both use cases in the selected region and corridor. To complete this task, the project team worked with PennDOT to identify one region and one corridor for preliminary assessment of two different use cases.

- The region selected was **Lehigh County** for assessment of the ADAS methodology.
- The corridor selected was **I-78/I-81** from the Maryland/Pennsylvania border to Allentown, PA for the assessment of the I2V use case.

In each scenario, the project team used the methodology explained in the previous Methodology section.

As detailed below, the ADAS assessment of Lehigh County totaled 47 out of 60, indicating a reasonable likelihood that Lehigh County will be a candidate for early adoption of lateral and longitudinal ADAS technologies. The I2V assessment of I-78/I-81 totaled 17 out of 20, indicating a high likelihood that the I-78/I-81 corridor will be a candidate for early adoption of I2V technology.

Instructions for following the rubric are detailed in **Appendix C**. The instructions provide a step-by-step process to follow the methodology for each use case and provide additional context on how the rubric was developed. Where applicable, the rubric scores were based on statewide averages for 2016-2020 as a score of "3."

LEHIGH COUNTY: ADAS USE CASE ASSESSMENT

SCORING DESCRIPTION & OVERVIEW

Partial automation is achieved by SAE Level 2 driver assist systems, which are currently available and becoming standard equipment on a growing number of light vehicles. The methodology evaluates this use case in the **regional (Lehigh County) context**. Due to the variety of ADAS technologies currently available, the score is broken into two components to match specific ADAS technology solutions to the identified problems and roadway characteristics in a region.

- The **lateral** applications component evaluates roadways for potential of strategies such as lane keeping and lane departure warnings.
- The **longitudinal** component evaluates roadways for potential of applications such as traffic jam assist or forward collision warning (Full list of CV safety application available here: https://www.its.dot.gov/infographs/index.htm).

ANALYSIS

The regional analysis consists of four main steps described in detail below:

- Step 1: Define region for consideration in the assessment.
- Step 2: Calculate the total length of roadway in the region in miles.
- Step 3: Evaluate Applicability of Lateral ADAS Applications.
- Step 4: Evaluate Applicability of Longitudinal ADAS Applications.

Step 1: Define region for consideration in the assessment.

- Region: Lehigh County

Step 2: Calculate the total length of roadway in the region in miles.

- **Length**: 768 miles
  - The project team selected the Roadway Management System (*RMS) – Segments External* dataset from PennDOT OneMap. In the data table settings, we selected length (ft.) of segments to be visible and downloaded the complete dataset. We filtered the full dataset by county code 39 to select Lehigh County segments only, summed the length (ft.) column and divided by 5,280 to calculate about 768 total directional miles of roadway in Lehigh County (all roads except local/non-classified roads).

Step 3: Evaluate Applicability of Lateral ADAS Applications

- **Step 3A***:* Is there a lateral-ADAS safety issue in the region?
  - Score: *5*
  - Crash rates above the statewide average score higher in the rubric (scores of 4-5) and indicate where ADAS technologies could be most beneficial, while crash rates below the statewide average score lower (1-2) indicating a region with less crashes related to the technology where deployment of lateral ADAS technologies may not provide large safety benefits. The project team used Pennsylvania Crash Information Tool (PCIT) to gather crash data by selecting a date range from January 2016 to December 2020, *Single Vehicle Run Off Road* crash event filter and the Lehigh County location filter. The total number of Single Vehicle Run Off Road crashes is 6,745 for an annual rate of 1,349 crashes in Lehigh County. We repeated this method for Head On/Opposite Direction Sideswipe crashes to calculate 329 crashes per year in Lehigh County. We summed both annual crash totals and divided by total miles of roadway in Lehigh County (calculated in Step 2) to calculate 2.2 crashes per year per mile, which is above the statewide average rate of 0.9 crashes per year per mile for these types of crashes. This yielded a **score of 5** to indicate that investment in ADAS technology in the Lehigh County region may be beneficial.
- **Step 3B***:* How recently have roads been resurfaced in the region?
  - Score: *2*
  - The project team used the *Pavement History* layer from PennDOT One Map. We used the *Layer Types* and *Layer Years* filters to calculate the total miles of concrete and asphalt roadways and the total miles resurfaced in the past 25 years or 10 years, respectively. We used the sequence number of 1 to identify the most recent layer put down on the roadway and identified roadways with Concrete Wearing (CW) or Bituminous (asphalt). We then filtered Layer Year by 25 or 10 years, respectively, and summed the segment lengths. The layer years are based on industry trends and consultations with PennDOT. In Lehigh County, there are 52 miles of concrete roadway, with 39 miles resurfaced in the last 25 years (75%). There are 629 miles of asphalt roadway with 143 miles resurfaced in the last 10 years (23%). The total number of concrete and asphalt does not add up to total miles of roadway analyzed in this effort due to a small number of roadways with recorded layer types that did not clearly identify them as either concrete or bituminous. The weighted average of recently repaved roadway is 27%. This yielded a score of 2 indicating Lehigh County is above the statewide weighted average of 19% for recently resurfaced roads and ADAS technologies can likely operate effectively on most of the County's roadways with existing pavement markings.
- **Step 3C***:* What is the quality of road markings in the region?

- Score: *5*
- This is a self-assessment for Lehigh County based on data from the *Pavement Marking Asset Management System* or local knowledge. The assessment is based on self-scoring estimation of pavement quality and prevalence of waterborne paint versus recessed tape. Waterborne paint is not as durable as recessed tape, so it requires more frequent maintenance. Without frequent restriping, waterborne paint pavement markings may not be as visible to ADS sensors compared to more durable recessed tape. The project team used data provided by PennDOT on District 5 recessed tape (durable paint) locations. We calculated the total length of segments of durable recessed tape to be 35.2 miles in Lehigh County, accounting for 4.5% of roadway. All other pavement markings in District 5 are waterborne, yielding a score of 5. This indicates a high use of waterborne paint that requires frequent maintenance. Restriping of roadways and adding durable paint can create more favorable conditions for ADAS technologies to be more effective.

- **Step 3D***:* Does the region have upcoming projects that could be leveraged?
  - Score: *5*
  - The project team used the MPMS projects *in development and future development* layer from PennDOT One Map. We downloaded the complete datasets for each and filtered improvement types to include only corridor safety improvement, guiderail improvements, new roadway, pavement preservation, resurfacing, and reflective pavement markers. We also filtered by county code 39 for Lehigh County. There are 77 projects identified as future development and 20 projects identified as in development. The project team also identified at least 4 Lehigh County projects identified as future infrastructure changes in the Eastern Regional Operational Plan. Summing up all the projects and dividing by total miles of roadway in Lehigh County, this yielded a score of 5 with 0.13 projects per mile. This was above the statewide average of 0.05 projects per mile. This indicated significant potential to add roadway improvements to planned projects to create more favorable conditions for lateral ADAS technologies.
- **Step 3E:** What is the average age of vehicles in the region?
  - Score: *2*
  - The project team used the National Household Travel Survey dataset. Vehicle age data is provided by MSA with more than 1 million people. Lehigh County does not fall into one of the three Pennsylvania MSAs with more than 1 million people. Therefore, we defaulted to the nationwide average vehicle age of 11.24 for vehicles in MSAs with less than 1 million people, yielding a score of 2.

Step 4: Evaluate Applicability of Longitudinal ADAS Applications

- **Step 4A***:* Is there a longitudinal-ADAS safety issue in the region?
  - Score: *5*
  - Crash rates above the statewide average score higher in the rubric (scores of 4-5) and indicate where ADAS technologies could be most beneficial, while crash rates below the statewide average score lower (1-2) and indicate a region with less crashes related to the technology where deployment of longitudinal ADAS technologies may not provide large safety benefits. The project team used the Pennsylvania Crash Information Tool to gather crash data by selecting a range from January 2016 to December 2020, *Rear End, and Back Up crash* filter, and the Lehigh County location filter. (Note: Back-up crashes refer to crashes that occurred in congestion or traffic backups.) The average annual rate for these crash types is about 1,172 crashes per year in Lehigh County. We divided by the total 768 miles of roadway to get a crash rate of 1.5 crashes per mile per year, which is above the statewide average of 0.5 crashes per mile per year, yielding a score of 5.

- **Step 4B***:* Is there congestion in the region?
  - Score: *5*
  - The project team used the *TSMO TomTom Travel Time Ratio (TTR) >2* layer in PennDOT One Map. Travel time ratio is the ratio of average travel time (minutes) to free flow travel time. For example, a 10-minute trip in peak period, which takes 5 minutes with no traffic is a ratio of 2. We used the TTR peak > 2 filters and county code 39 to sum all segment lengths in Lehigh County to calculate there are 65 miles of roadway in Lehigh County with significant congestion, representing about 8% of the roadways. The 8% congestion indicator is above the statewide average of 4%, resulting in a score of 5. This indicates sufficient areas within Lehigh County where longitudinal ADAS technologies, such as traffic jam assist or forward collision warning, could be useful in recurring congestion.
- **Step 4C**: Are there traffic bottlenecks in the region?
  - Score: *5*
  - The project team used the TSMO *Major Traffic Bottleneck (2018)* layer in PennDOT One Map, filtered by county code for 39 for Lehigh County. We sorted the bottleneck rankings from highest (worst) ranked bottleneck in region. The bottleneck rankings in Lehigh County ranged from 38 to 22,803 (out of 22,838) The lowest number ranking (more severe bottleneck) ranked 38th in the Commonwealth yielding a score of 5. This indicates significant bottlenecks in the region that may be an indicator longitudinal ADAS technologies may help to avoid congestion-related crashes, such as traffic jam assist or forward collision warning.
- **Step 4D**: Are there known areas in the region with recurring foggy conditions?
  - Score: *1*
  - The project team used data provided by District 5 from the Sign Asset Management System. *No fog area* signs were identified as located in Lehigh County, yielding a score of 1. This indicates limited areas where longitudinal ADAS applications could be deployed to avoid rear-end and back-up crashes in low-visibility or fog-related conditions. However, locations of fog areas may be supplemented by local knowledge during this self-assessment.
- **Step 4E**: Does the region have high-speed approaches to signals?
  - Score: *5*
  - The project team used data provided by District 5's Sign Asset Management System. The dataset identified 24 *signal-ahead* signs in Lehigh County, yielding a score of 5. These signs indicate high speed and/or low visibility approach intersections in the region where longitudinal ADAS applications could be deployed to avoid rear-end and back-up crashes.
- **Step 4F**: Does the region have upcoming projects that could be leveraged?
  - Score: *5*
  - The project team used the MPMS projects *in development and future development* layers from PennDOT One Map. We downloaded the complete datasets for each and filtered improvement types to include only corridor safety improvement, lighting, and VMS. We also filtered by county code 39 for Lehigh County. There are 5 projects identified as future development and 18 projects identified as in development. The project team also identified at least 1 Lehigh County project identified as a future project in the Eastern Regional Operational Plan. Summing up all the projects and dividing by total miles of roadway in Lehigh County (768 miles), this yielded a score of 5 with 0.03 projects per mile. This

indicates significant potential to add roadway improvements to planned projects to create more favorable conditions for longitudinal ADAS technologies.

- **Step 4G:** What is the average age of vehicles in the region?
  - Score: *2*
  - The project team used the National Household Travel Survey dataset. Vehicle age data is provided by MSA with more than 1 million people. Lehigh County does not fall into one of three Pennsylvania MSAs with more than 1 million people. Therefore, we defaulted to the nationwide vehicle age for vehicles in MSAs with less than 1 million people of 11 years, yielding a score of 2.

RECOMMENDATION

For Lehigh County, the total lateral **score was 19 out of 25**, while the total longitudinal **score was 28 out of 35**, for a combined **score of 47 out of 60**. For the ADAS methodology, a region score can be evaluated as a combined lateral and longitudinal score. Alternatively, regions may be considered for specific technologies or support if a high score exists in only one category. For Lehigh County, the results show similar scores for both the lateral and longitudinal assessments. Overall, the combined score received approximately 77% of the possible points, suggesting it is a reasonable candidate for locations where ADAS technology is likely to provide early benefits. If funding does not allow investing in both lateral and longitudinal ADAS-supporting improvements in Lehigh County, it would be reasonable to invest in either one to still achieve some safety benefit.

I-78/I-81 CORRIDOR: I2V USE CASE ASSESSMENT

SCORING DESCRIPTION & OVERVIEW

PennDOT is in a strong position to accelerate I2V connected vehicle applications of traveler information systems. The methodology evaluates this use case in the **I-78/I-81 corridor context**. Due to the variety of I2V applications currently available, the score is broken into multiple components to match specific technology solutions to the identified problems and roadway characteristics in a corridor.

ANALYSIS

The Corridor analysis followed seven steps described in detail below:

- Step 1: Define corridor for consideration in the assessment. It should be a contiguous stretch of pavement and include the full extent of potential project limits.
- Step 2: Calculate the total length of roadway in the corridor in miles.
- Step 3: Are there existing ITS devices on the corridor that provide information or feedback to motorists?
- Step 4: Are there traffic bottlenecks on the corridor?
- Step 5: Is there a safety issue in the region?
- Step 6: Does the region have upcoming projects that could be leveraged?
- Step 7: Are signals in the corridor connected to the PennDOT network?

Step 1: Define corridor for consideration in the assessment. It should be a continuous stretch of pavement and include the full extent of potential project limits.

- **Corridor:** I-78/I-81 from the MD/PA border to Allentown, PA

Step 2: Calculate the total length of roadway in the corridor in miles.

- Miles: *296*
  - Measuring from the MD/PA State Line to I-78 exit 60 near Allentown, the corridor measures 148 miles in each direction. Therefore, the total length of roadway for this assessment equals 296 miles.

Step 3: Are there existing ITS devices on the corridor that provide information or feedback to motorists?

- Score: *5*
- The project team utilized the PennDOT One Map ITS Devices layers for Dynamic Message Signs, Highway Advisory Beacons & Radios, and RWIS Stations. A total of 56 devices were counted along the corridor, or 0.18 devices per mile, resulting in a score of 5. Although some devices are co-located and may not represent 56 individual locations where information is currently disseminated, the density of ITS devices on this corridor exceeds the statewide average of 0.02 devices per mile.

Step 4: Are there traffic bottlenecks on the corridor?

- Score: *5*
- The project team utilized the PennDOT One Map layer TSMO - Major Traffic Bottlenecks – 2018. Using the RANKING variable, we filtered to only include the top 5,000 locations (ranking less than or equal to 5,000). Numerous segments of the assessment corridor fell within the top 5,000 bottleneck locations. Several sections of the corridor are within the top 250 locations. This analysis resulted in a score of 5.

Step 5*:* Is there a safety issue in the region?

- Score: *4*
- The project team used Pennsylvania Crash Information Tool to gather crash data by selecting a date range from January 2016 to December 2020, Interstate – Yes roadway filter and polygon location filter around the assessment corridor. The total number of crashes over 5 years was 5,502, with an annual high of 1,225 in 2018 and low of 1,003 in 2020, for an average annual 1,100 crashes on the assessment corridor. We divided the high, low, and average annual crashes by total miles of roadway (calculated in Step 2) to calculate 3.4 - 4.1 crashes per year per mile, which is above the statewide average of 2.1 crashes per year per mile, yielding a score of 4.

Step 6: Does the region have upcoming projects that could be leveraged?

- Score: *3*
- The project team used the MPMS projects in development and future development datasets from PennDOT One Map. We downloaded the complete datasets for each and filtered improvement types to include only Corridor Safety Improvement, Intersection Improvement, Safety Improvement, and VMS. We also filtered by State Route Numbers 0078 and 0081 for the assessment corridor. There are 0 projects identified as future development and 3 projects identified as in development. Summing up all the projects and dividing by total miles of roadway, this yielded a score of 3 with 0.01 projects per mile, which is equal to the statewide average.

Step 7: Are signals on the corridor connected to the PennDOT network?

- Score: N/A

- The assessment corridor is completely interstate, so this step is not applicable. As a result, the total score for this assessment is out of a maximum 20 points, not 25.

RECOMMENDATION

For the I2V application, a corridor score can be evaluated as a combined existing device, safety, congestion, and signals score. Alternatively, corridors may be considered for specific technologies or support if a high score exists in one only category. The I-78/I-81 corridor scored 5 out of 5 in the ITS Devices and I2V Congestion scores, as well as 7 out of 10 in the I2V Safety Score. The corridor includes only interstate roadways, so there are no signals component to the score. Overall, the corridor scored 17 out of 20 possible points.

These results indicate the corridor has a high likelihood of early deployment of I2V technology. Since I2V technology deployment is largely driven by infrastructure owner/operators rather than private entities, and because this corridor is under state maintenance, PennDOT has a strong opportunity to deploy I2V devices along this corridor, specifically as it relates to ITS and congestion devices. The timing of such deployment is largely dependent on the adoption rate of connected vehicles able to receive messages from the infrastructure; however, once a suitable adoption rate is achieved, it would be reasonable to include the I-78/I-81 corridor among the first to receive I2V technology. I2V connected vehicle applications could include traveler information systems, such as Road Weather Information Systems and travel information messaging. These systems are being pilot tested in the USDOT Connected Vehicle Pilot Deployment Program in Wyoming. Other examples of I2V include Integrated Corridor Management, work zone warnings, and curve speed warnings.

ASSESSMENT NOTES

Through the analysis of the two example use cases, the project team identified several future considerations to tweak the methodology and tips for analysts performing the use-case assessments. For the remaining use cases not part of the two example assessments, the project team identified all dataset sources for to assist future analysis in completing the assessment, along with a “Tips and Tricks” (**Appendix D**) for some of the database sources. For all self-scoring variables, the project team also identified a potential data source.

FUTURE CONSIDERATIONS

This tool is intended to evolve over time and additional variables may be considered in the future. For example, the methodology could include a variable that self-scores a corridor or region that starts/ends at a state line on the level of cooperation and likelihood the border state is likely to support the extension of the deployment, such as automated trucking. For some use cases, such as I2V, agencies may consider adding an infrastructure readiness self-scoring assessment. This variable would evaluate the level of effort needed to upgrade existing infrastructure to be compatible with technology (e.g., signal controllers). Where applicable, the rubric scores were based on statewide averages for 2016-2020 as a score of “3.” The rubric scoring should be periodically updated to account for any changes and tweak the scoring rubrics appropriately.

APPENDIX A: LITERATURE REVIEW AND NATIONAL SCAN

The Operational Domain Environment varies by CAV use case. Components of the ODD include:

- Physical infrastructure (roadway types, surfaces, edges, and geometry)
- Operational constraints (speed limit and traffic conditions)
- Objects (signage, roadway users, and non-roadway user objects/obstacles)
- Connectivity (vehicle, traffic information, remote fleet management system, infrastructure sensors
- Environmental conditions (weather, roadway conditions, particulate matter, illumination)
- Zones (geo-fencing, traffic management zones, school/construction zones, and regions/states)

ODD can be looked at from different perspectives, and what is most important for this study is to understand what is important to assess CAV readiness. When considering where private companies will choose to deploy, infrastructure readiness is a key consideration and something that agencies like PennDOT have at least partial control of influencing through a combination of investment, policy, and awareness. This study focused on physical infrastructure because it's a component of the ODD that PennDOT has an opportunity to influence. For the physical infrastructure component of the ODD, below are example roadway type deployment environments.

EXAMPLE ROADWAY TYPE OPERATIONAL DESIGN DOMAINS

1. Sidewalk and off-road
    a. Examples: Personal delivery devices, automated personal transport, food delivery robots.
    b. Low speed (less than 15 miles per hour).
    c. Operate on sidewalks, pathways, and other non-road assets; May also operate on the road at low speeds.
    d. May need dedicated right of way or path for pilot.
2. Dedicated lane
    a. Examples: Campus and city shuttles, downtown circulators, airport people movers.
    b. Typically, lower speeds (less than 25 miles per hour), but dedicated thoroughfares for 55-miles per hour and higher are possible.
    c. Lane could be on shared-use roadways or specific to a use case.
    d. May need dedicated ROW and/or specific infrastructure improvements on shared-use roads.
3. Shared road use (Collectors and Arterials)
    a. Examples: Downtown circulators, automated ride-hailing, CAV transit, CAV personal use.
    b. Operate at or below speed limit of roadways, within the ODD defined by the Original Equipment Manufacturer (OEM) and within any additional guidelines specified by NHTSA if applicable.
    c. Operations can be enhanced with pavement markings and signing, but generally still rely on detailed digital mapping.
4. Shared road use (Highways and Interstate)

a. Examples: automated and platooning commercial vehicles, CAV personal use, production passenger vehicles with V2I connectivity, automated ride-hailing.
b. Operate at design speeds of roadways greater than 45 miles per hour, typically within NHTSA guidelines or with a special exemption for on-road use.
c. High-speed operations often augmented by teleoperations or manual inputs from safety driver.
d. ADAS rely on pavement markings and signing.

PLATOONING COMMERCIAL VEHICLES AND AUTONOMOUS TRUCKING

Note: Based on industry trends, this use case evolved into automated trucking. Truck platooning is a steppingstone to full automation on limited access highways.

Platooning is the movement of a fleet of vehicles controlled as one unit by CAV technology. In some deployments, only longitudinal operations are coordinated as a single unit while lateral operations are controlled separately. In others, both longitudinal and lateral operations may be controlled as one unit. Platooning can reduce travel time for freight by optimizing the distance between trucks in a platoon; optimizing the driving time and minimizing the idle time; and adjusting speed as the vehicles are able to communicate with each other thus avoiding the delayed response time of a human driver. This leads to reduction in air drag and allows for more vehicles on the roadway. In a platoon, the following trucks stay in lane, measure the distance between vehicles, and brake automatically within fractions of a second should the lead or other vehicle(s) in front reduce speeds. Truck platooning uses cooperative adaptive cruise control (CACC) technology and can aid in fuel savings and improved safety benefits.

DESIGN ENVIRONMENT

Platooning is generally applied to long-haul trips, with multiple vehicles heading the same direction platooned on high-speed limited access roadways. State DOTs such as Minnesota DOT and PennDOT have developed platoon operating constraints and requirements that need to be considered. The Pennsylvania-specific constraints include:[13]

- Platooning vehicles can operate only on approved limited access highways or interstate highways. Vehicle platooning routes and maps are usually provided by states on their websites.
- Up to three vehicles may platoon together, given that an operation plan has been approved by authorities.
- Each vehicle shall maintain a headway of at least 40 feet when traveling over bridges.
- Platooning vehicles must disengage when they are operating on a roadway with hazardous grade speed limit; entering a work zone when workers are present; or entering or driving within toll plazas.
- Vehicles carrying hazardous materials, liquids, loose loads, livestock, or truck and pole combinations etc. should not be permitted to engage in vehicle platoons.
- A serialized sticker indicating that the vehicle is capable of being part of a platoon should be displayed on driver and passenger side of power unit, close to other federal and state regulated stickers.

[13] Vehicle Platooning Policy

In addition, the Competitive Enterprise Institute also recommends rules regarding exemptions for Following-Too-Closely (FTC) which includes reasonable and prudent, time, distance, and sufficient space to enter and occupy without danger by vehicle class (cars, heavy trucks, and caravans). Rules differ from state to state.[14]

BEST PRACTICES

Best practices regarding platooning commercial vehicles include:[15]

- Consideration of more than one depot of origin allowing possibility of forming on-the-fly platoons and not only the early planning of platoon services.
- Strengthening of ties and cooperation with all relevant stakeholders is crucial for promoting wide-spread introduction of platooning.
- Consideration of geographic dependencies with more applicability in good weather areas and areas with limited access highways and light traffic.[16]
- Creation of a methodology and statewide ranking system for roadways applicable to platooning.
- Assessment of structures for heavy loads and recovery time to determine headways and other factors.

SELECT PILOTS AND DEPLOYMENT TIMELINE

Key players in this market include Peloton Technology, Locomation, Volvo, OTTO Motors, and Omnitracs.

- The University of California, Berkley's Partners for Advanced Transportation Technology (PATH) Program has pioneered a number of platooning technologies since 1994.[17]
- In 2018, Volvo Group, FedEx, and the North Carolina Turnpike Authority (NCTA) successfully demonstrated truck platooning.[18]
- More recently, a Forbes article indicated that USDOT Federal Highway Administration (FHWA) is likely to conduct a Field Operational Test of first-generation truck platooning on the road in 2021.[19]

PUBLIC OPINION

Widespread acceptance by the public at large as well as by other highway road users is dependent on phased implementation.[20]

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[14] Authorizing Automated Vehicle Platooning: A Guide for State Legislators, 2019 Edition

[15] Analysis of the operational and environmental benefits of truck platooning in freight transport: the case study of Luís Simões

[16] ITS Deployment evaluation Executive Briefing – Truck Platooning

[17] A Brief History of Truck Platooning

[18] Truck Platooning Market - Growth, Trends, Covid-19 Impact, And Forecasts (2021 - 2026)

[19] U.S. States Are Allowing Automated Follower Truck Platooning While the Swedes May Lead in Europe

[20] Truck Platooning Timeline Through 2030

PERSONAL DELIVERY DEVICES

Note: This section discusses the automated parcel delivery use case as a broad category. Personal delivery devices are a subset of this use case that was selected.

Automation in parcel delivery involves use of technology that can automate the last mile component of parcel delivery i.e., the distance from a local depot to a final destination, and offer an efficient, quick, and inexpensive way to hand parcels to their respective recipients.[21] The robots can independently deliver parcels and packages, or they can follow delivery people freeing them from having to carry items or reduce the times they need to go back and forth to the delivery truck.[22]

DESIGN ENVIRONMENT

Automated parcel delivery robots can be categorized by the environment in which they operate:[23]

- Air-based delivery involving use of unmanned arial vehicles e.g., drones and copters to safely take packages to customers.
- Road-based delivery pertaining to the use of small self-driving vehicles that travel on low-speed and local roads to deliver packages.
- Ground-based delivery, which operates driverless robots on sidewalks to distribute packages.

These technologies are more likely to be piloted and deployed where digital infrastructure is available or easily acquired that goes beyond traditional transportation assets, such as 3D mapping of sidewalks and origin/destination information for food delivery.

BEST PRACTICES

Best practices for automated parcel delivery services include:

- A focus on ground-based delivery. Most of the automated parcel delivery technology fit into ground-based delivery. Key players in this market include, Postmates Serve, Kiwibot, Starship, and Marble.[24] Antybotics and Continental invented a hybrid solution in which a road-based autonomous van carries robotic dogs to a particular area. Then, the robotic dogs, a ground-based solution, carry the packages to the final destination.[25] Nuro and Robomart are among two examples of road-based automated parcel delivery and the can serve multiple destinations in one tour. While Nuro is loaded with specific packages that are requested by recipients, Robomart is loaded with a pre-defined set of goods. Users can request the closest Robomart in the area, unlock the vehicle and purchase goods in a "grab-and-go" manner.[26]
- Air-based automated parcel delivery technology varies significantly in terms of their payload and range. While Amazon Prime Air can currently carry packages up to 5 pounds, Elroy can carry loads of 150 pounds for 300 miles.

[21] The Top Ten Autonomous Delivery Solutions of 2018

[22] Summary Report: Public Perception of Delivery Robots in the United States

[23] The Top Ten Autonomous Delivery Solutions of 2018

[24] 8 Robots Racing to Win the Delivery Wars Of 2019

[25] 8 Robots Racing to Win the Delivery Wars Of 2019

[26] The Top Ten Autonomous Delivery Solutions of 2018

- An understanding of delivery location accuracy is necessary. Robots such as Amazon Prime Air will land close to the recipient designated location and confirm the package was delivered, however, robots such as Zipline do not land. They fly low as they approach the destination and drop the package using parachutes before flying back to the depot.[27]

SELECT PILOTS AND DEPLOYMENT TIMELINE

- Several automated parcel delivery services are already operational. For example, Serve is deployed in Los Angles, Starship has around 100 robots deployed in 8 cities across the UK and US, Kiwibots are serving UC Berkley's campus, and DHL Parcelcopter can make fully autonomous deliveries through harsh environments of the Alps.[28]
- Domino's Pizza has partnered with Nuro to pilot an automated pizza delivery service in Houston, Texas.[29] Domino's is the first quick-service restaurant company in the U.S. to launch autonomous pizza delivery. The company previously tested self-driving delivery with Ford, with a vehicle that was staffed by a safety driver. However, this marks the first time Domino's will offer a fully autonomous delivery experience.[30]

PUBLIC OPINION

A study conducted by the United States Postal Service had the following findings:[31]

- Seven in ten U.S. residents would consider receiving deliveries from "unaccompanied robots", however, 24 percent would always prefer to receive their deliveries from a person even if it cost more or took longer to receive their shipment.
- Most of those surveyed believe that "independent delivery robots" could offer a more flexible delivery experience, and around 1 in 3 say that they would be willing to pay slightly more to receive those benefits.
- The respondents concern about "unaccompanied robots" stem from the possibility of theft and job losses for carriers.

CONNECTED TRANSIT VEHICLES

Note: V2I Transit is a subset of this use case that was selected.

Connected transit vehicles leverage automated and connected vehicle technologies to improve the performance of transit operations by increasing efficiency, reliability and safety while reducing financial costs. Transit vehicles can be connected to each other and other vehicles (V2V), to the infrastructure (V2I) and to passengers or other road users (V2X). A few examples of connected transit technology include transit signal priority, warnings to pedestrians and bicyclists, and driver assistance.

[27] The Top Ten Autonomous Delivery Solutions of 2018
[28] DHL Drone Delivery and Parcelcopter Technology
[29] The Future of Delivery is Self-Driving
[30] Domino's® Tests Autonomous Delivery with Nuro in Houston
[31] Summary Report: Public Perception of Delivery Robots in the United States

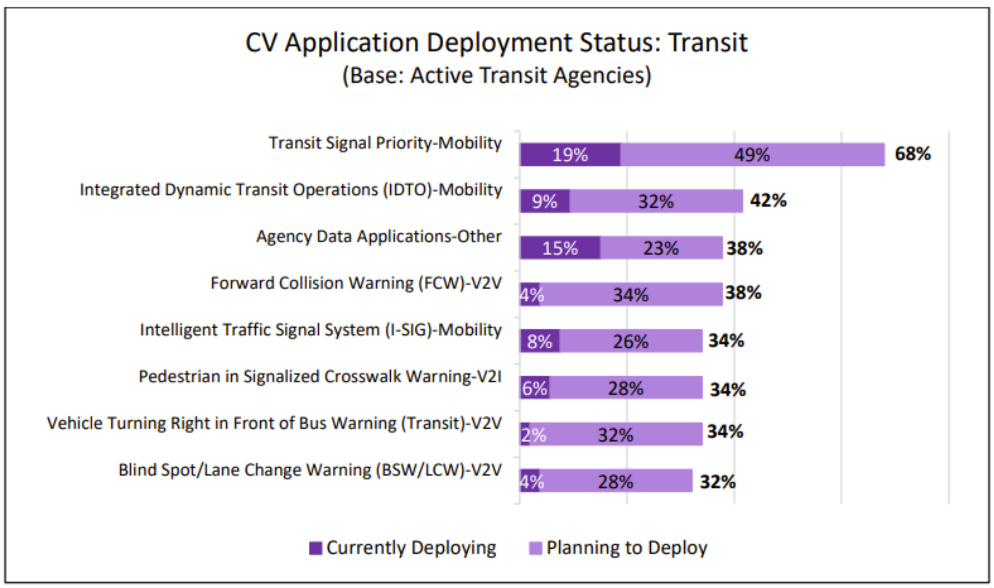
DESIGN ENVIRONMENT

The design environment for connected transit is general dedicated lanes or shared road collectors and arterials.

- Connected transit technology is primarily used to provide transit signal priority and improve pedestrian, bicyclist, and motorist safety in areas where a conflict between them is likely.[32] As a result, most of the CV deployments in transit pertains to intersections.
- Pedestrian and bicycle safety at transit stops when the transit vehicle is pulling into the bus stop area is another area that CV technology can improve safety.
- Arrival information and real-time vehicle tracking are additional uses of connected transit technologies, which can apply to specific routes or the entire fleet.

BEST PRACTICES

Figure 3 shows eight most prevalent CV technologies that are either being used or are planned to be used by agencies.



Source: USDOT

Figure 3. Transit CV deployment, percent planned or deployed (USDOT).

Other practices include:[33]

- **Pedestrian Warning Systems:** Transit vehicles automatically beep or announce messages to pedestrians when a bus is turning.

[32] Automated And Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, And Pedestrian Safety: Technical Report

[33] Intelligent Transportation Systems Deployment: Findings from the 2019 Connected Vehicle and Automated Vehicle Survey

- **Driver Assistance System for Shoulder Running Buses:** Warning system helping drivers to keep the bus centered on the shoulder by providing feedback to drivers using haptic feedback devices located on the seat, as well as a suggestive opposite torque when the driver is steering away from the center of the shoulder.
- **Connected Intersections and Mobile Apps:** Warning system using smartphone technology to increase pedestrians and bicyclist's awareness of their surroundings and transit vehicles around them.
- **Connected Transit and Mobile Apps:** A traveler safety app that enables individuals to share their location with a transit vehicle. The transit vehicle can dwell at the stop giving the individual more time to catch the vehicle.[34]

SELECT PILOT AND DEPLOYMENT TIMELINE

Vehicle based safety systems are beginning to be offered by vehicle manufacturers, similar to the consumer market for collision and lane change warning systems. However, transit fleets generally turn over slowly and follow long procurement processes, so the market adoption will likely be slower than with passenger vehicles.

- The Multimodal Intelligent Traffic Signal System (MMITSS) Prototyping and Field Testing project in Utah, sponsored by FHWA, is a comprehensive traffic signal system taking advantage of the connected vehicle environment for multiple transportation modes, including general passenger vehicles, transit, emergency vehicles, freight vehicles, and pedestrians.[35]

PUBLIC OPINION

Public opinion regarding connected transit vehicles could not be identified. It is likely that transit riders would not be able to determine if a vehicle were using connected technology (such as transit signal priority), although persons outside of the vehicle using connected apps like Connection Protection or NextBus might observe the connected information sharing features (such as using Connection Protection to request the bus holds so they can make a transfer, or tracking a bus along its route with arrival time information in NextBus).

CONNECTED AND AUTOMATED PERSONAL USE VEHICLES

Note: ADAS is a subset of this use case that was selected.

Connected and automated personal vehicle technologies include robotics, sensors, and advanced software to automate different elements of the vehicle such as steering, acceleration, or braking. While there is general agreement that the ultimate preferable configuration of vehicles of the future for personal use will be both connected and automated, the technologies that support these endeavors are developing both synergistically and separately. A CV is a vehicle that can communicate with other vehicles, infrastructure, or other wireless technologies. CVs today typically communicate using Wi-Fi, a cellular network, Dedicated Short Range Communications (DSRC), or Cellular Vehicle-to-Everything (C-V2X) radio frequencies. CVs use a variety of equipment to sense, collect, and transmit real-time data, such as road or traffic conditions, weather conditions, vehicle speeds, etc. There are three key types of vehicle communications:

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[34] Applications Of Connected Vehicle Infrastructure Technologies to Enhance Transit Service Efficiency and Safety

[35] Multimodal Intelligent Traffic Signal System (MMITSS) Prototyping and Field Testing

- V2V: Vehicle to vehicle communication
- V2I: Vehicle to infrastructure communication
- V2X: Vehicle to Internet-of-Things (IoT) communication

Also known as driverless cars or self-driving vehicles, AVs are equipped with sensors (e.g., cameras, radar, LiDAR, computer vision, GPS, etc.) which allow onboard computers to perform some or all driving tasks. The AV industry is currently categorized by the levels of automation as defined by the SAE, displayed in **Figure 1**.

DESIGN ENVIRONMENT

The ODD for connected and automated vehicles includes environmental, geography, and time-of-day constraints, as well as the presence or absence of certain traffic or roadway characteristics.[36] They can operate in shared lanes of varying class, depending on the specific technology. The Center for Automotive Research published a report that documents the impacts of existing road infrastructure and need for new infrastructure for the application of CAV technology. These include:[37]

- Performance characteristics of road markings can affect the ability of machine vision systems. Improving road markings will help accelerate the safety benefits, but developers understand that the technology cannot solely rely on lane markings to operate safely.
- Traffic infrastructure and signs should be updated to use V2I applications and high-definition 3D mapping to improve traffic capacity and flow. Moreover, V2I and V2V technology will help boost efficiency of traffic flow and the same amount of traffic can be accommodated on fewer road lanes. Vehicles will be able to platoon safely and will thereby result in fewer crashes, which is the cause of 25% of traffic congestion.
- Lane width can be reduced if CAV dimensions remain constant. This can lead to road diets and medians can be removed or narrowed. The space saved can be used for wider sidewalks, green spaces bike lanes etc.
- Infrastructure needed to support V2I communication include RSUs, traffic signal controllers, traffic management center, backhaul communications etc.

According to the UC Berkley's PATH Program, managed lanes are ideal test beds for CAVs. Following are the site selection criteria for CAV testing and deployment on managed lanes in California:[38]

- At least 10 miles of continuous lane.
- Enough congestion in general purpose lanes to provide incentive but not too much congestion in the managed lanes.
- Remain active during both morning and evening peak hours in both directions.
- In existence already, under construction, or expected to be available for public use no later than 2020.
- Include some diversity of physical configurations
  - physically segregated lanes
  - lanes with discrete access points
  - lanes with continuous access

[36] Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon

[37] Planning For Connected and Automated Vehicles

[38] Early Opportunities for AV Deployment in California Managed Lanes

Signal Phase and Timing messages can be used at isolated intersection or along corridors. The SPaT challenge, an initiative of the V2I Deployment Coalition led by AASHTO, challenged state and local public sector transportation Infrastructure Owners and Operators (IOOs) to deploy DSRC infrastructure with SPaT broadcasts in at least one coordinated corridor or network in each state.[39]

BEST PRACTICES

The following actions should be considered for CAV impact and deployment in the short to medium term by government entities:[40]

- Local agencies should examine zoning requirements including parking requirements, specifications for site design, and specifications for parking lots and garages.
- Tracking lane-keeping technology is crucial as currently, vehicles rely on pavement markings and signage to stay in their lane. In Michigan, poor markings are a result of low funding opportunities and weather conditions. Road agencies should track how vehicle developers and manufacturers are handling CAV lane-keeping technology.
- Agencies should ensure that CAVs have real-time and accurate information about detours, construction, and road hazards. This includes monitoring intersection design and signal infrastructure.
- Agencies should provide guidance, information, and training to prepare the workforce and public for operation and use for CAVs.
- When drafting legislation, state legislatures should use terminology developed through technical standards, such as SAE terminology.[41]

SELECT PILOTS AND DEPLOYMENT TIMELINE

Since the use case of CAV personal use vehicles encompasses a broad set of technologies, pilot and deployment timelines for each technology vary.

- The PATH Program indicates that level 1 and level 2 AV systems are already on the road; however, level 3, level 4, and level 5 systems are currently being tested but deployment timeline is uncertain.[42]
- According to Minnesota Governor's Council on Connected and Automated Vehicles report, California authorized Waymo, Cruise, Nuro, Zoox, and AutoX to conduct driverless testing on public roads in 2020. Market penetration of CAVs is estimated to be below 10% in the near term (2020 – 2025), between 10% and 75% in the mid-term (2025 – 2035) and 75% to 100% in the long term (beyond 2035).[43]
- Other studies and surveys show that self-driving cars will be operational closer to 2050; 15% of the public and 20% of governments also indicated that they believe CAVs will never be fully deployed.[44]

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[39] AASHTO SPaT Challenge Webinar

[40] Planning For Connected and Automated Vehicles

[41] Automated Vehicles 3.0: Preparing for The Future of Transportation

[42] Early Opportunities for AV Deployment in California Managed Lanes

[43] Minnesota Governor's Council on Connected & Automated Vehicles

[44] Minnesota Governor's Council on Connected & Automated Vehicles

PUBLIC OPINION

Public opinion on CAVs has been more heavily studied than most other use cases:

- A study was conducted by The University of Texas at Austin where 1,088 respondents were surveyed:
  - Results indicate that only around 29% of Texans are not interested in owning or leasing Level 4 AVs (if affordable).
  - Among Texans who are interested in AVs, most would let their vehicle drive on freeways (around 61%) but are least comfortable riding in AVs on congested streets (36.1%).
  - Emergency notifications in an event of an accident (around 72%) and vehicle health reporting (around 69%) are the two connectivity features of greatest interest to Texans.[45]
- A separate study was conducted by The University of Texas at Austin where 358 respondents were surveyed.
  - Results indicated that higher-income, technology-savvy males, who live in urban areas, and those who have experienced more crashes have a greater interest in and higher Willingness-To-Pay (WTP) for the new technologies, with less dependence on others' adoption rates.
  - This information is useful to simulate long-term adoption of CAV technologies under different vehicle pricing and demographic scenarios. These results can be used to develop smarter transportation systems for more efficient and sustainable travel.[46]
- A national public opinion survey was conducted by HNTB to understand the public's perspectives of autonomous vehicles. Based on the survey results, Americans remain concerned about the use of autonomous vehicles. Other findings include:[47]
  - Approximately 52% of Americans surveyed believed that they are knowledgeable or familiar with autonomous vehicles.
  - Almost six in ten (58%) believe they will be in commonplace within the next 10 years.
  - Increased mobility for non-drivers is recognized as the single most important benefit of autonomous vehicles.

PRODUCTION PASSENGER VEHICLES WITH VEHICLE-TO-INFRASTRUCTURE CONNECTIVITY

Note: I2V is a subset of this use case that was selected.

V2I and I2V communication refers to the data exchange between vehicles and road infrastructure through wireless and typically bi-directional connections. This type of communication comprises hardware, software, and firmware;

[45] Are We Ready to Embrace Connected and Self-Driving Vehicles? A Case Study of Texans

[46] Assessing Public Opinions of And Interest in New Vehicle Technologies: An Austin Perspective

[47] America THINKS: Sharing the Road with Autonomous Vehicles - 2019

infrastructure components such as lane markings, road signs, and traffic lights can wirelessly share information to the vehicle and vice versa.[48] Examples of V2I applications include:[49]

- Spot Weather Impact Warning: Designed to detect unsafe weather conditions, such as ice or fog, and notify the driver if reduced speed or an alternative route is recommended.
- Eco-Approach and Departure at Signalized Intersections: Alerts drivers of the most eco-friendly speed for approaching and departing signalized intersections to minimize stop-and- go traffic.

V2I communication in personal vehicles could possibly reduce 90% of traffic fatalities caused due to human error, saving approximately 30,000 lives in the United States and $190 billion in health care costs.[50]

To increase effectiveness of V2I technologies, road infrastructure will need to move from an analog world to a digital world, involving lower human interaction such as display messages designed for human eyes to digital messages designed to communicate with CV technology.[51] The mode of communication for V2I technologies and applications continues to be debated.

DESIGN ENVIRONMENT

V2I technologies span a wide range of environments and infrastructure including low and high speed as well as urban and rural roadways.

- V2I sensors are used in intelligent transportation system (ITS) to capture data from road users and issue real-time advisories to road users about various incidents on the road including traffic congestions, construction sites, road conditions and parking zones.[52]
- SPaT messages rely on I2V technology to communicate the signal status to a vehicle allowing for coordination of vehicle speed.[53]
- Common V2I technologies that have already been released for public use include:[54]
    - Smart Parking: Assists drivers in finding open parking spaces by sharing instantaneous results on available parking. This is indicated by red or green lights above parking stalls.
    - Smart Signal Control Infrastructure: The infrastructure includes sensors and cameras which detect how many vehicles are in each lane and whether a car is waiting. It then calculates the time it will take to clear each side of the street but also provides alerts such as pedestrian arrival at signal, emergency vehicles, approaching red light and countdown to signal change to make quick changes for improved traffic flow and safety. Smart traffic lights can work in tandem with other smart lights and connect with the city network of signals to improve traffic throughout.
    - Smart Signs: Wireless digital traffic signposts can transmit road sign information to the vehicle dashboard, the driver's head-up display, or be narrated to the driver through voice activation.

[48] What Is Vehicle-To-Infrastructure (V2i) Communication and Why Do We Need It?

[49] Vehicle-To-Infrastructure Technologies Expected to Offer Benefits, But Deployment Challenges Exist

[50] Ten ways autonomous driving could redefine the automotive world

[51] What Is Vehicle-To-Infrastructure (V2i) Communication and Why Do We Need It?

[52] What is Vehicle-to-Infrastructure Technology?

[53] What is Vehicle-to-Infrastructure Technology?

[54] What You Should Know About Vehicle-to-Infrastructure Communication

BEST PRACTICES

The USDOT provides best practices for communication technologies based on CV pilot deployments.[55] These include:

- Development of Over-The-Air (OTA) firmware updates for the Onboard units (OBUs).
- Development of OBU installation procedures which varies by vehicle model and year.
- Obtaining FCC licensing for RSUs for deployment in sites.
- Refine proper antenna placement to reduce communications interferences.

SELECT PILOTS AND DEPLOYMENT TIMELINE

- In January 2019, Ford announced their commitment to deploy C-V2X technology in all their new vehicle models in the United States beginning in 2022.[56]
- According to USDOT, V2I technology will be deployed in the United States over a 20-year period as existing infrastructure is replaced or upgraded.[57]
- USDOT mentioned that V2I will capitalize on V2V, and deployment will lag behind V2V rulemaking. AASHTO estimated that 20 percent of signalized intersections will be V2I-capable by 2025, and 80 percent of signalized intersections would be V2I-capable by 2040.[58]

PUBLIC OPINION

Based on findings from a case study conducted by the University of Texas at Austin where 1,088 respondents were surveyed, the longer a driver has been licensed, the more willing they are to pay for adding DSRC-based connectivity to their current and existing vehicles.[59]

LITERATURE REVIEW REFERENCES

Table 1. Literature Review References

Reference Footnote #	Title	Date Published/ Last Updated	Agency/ Source
	Design Environment, Best practices, and Timeline by Potential Use Case		
1	Pennsylvania Joint Statewide Connected and Automated Vehicles Strategic Plan	Jul 2018	PennDOT

55 ITS Development Evaluation Executive Briefing: Connected Vehicle Pilot Deployment Program

56 Ford commits to deploy C-V2X technology on all new vehicles in the US beginning in 2022

57 Vehicle-To-Infrastructure Technologies Expected to Offer Benefits, But Deployment Challenges Exist

58 Vehicle-To-Infrastructure Technologies Expected to Offer Benefits, But Deployment Challenges Exist

59 Are We Ready to Embrace Connected and Self-Driving Vehicles? A Case Study of Texans

Reference Footnote #	Title	Date Published/ Last Updated	Agency/ Source
2	Florida Department of Transportation (FDOT) Connected and Automated Vehicle Initiative	Jan 2021	FDOT
3	Connected Vehicle Deployment Plan	Feb 2021	GDOT
4	Concept of Operations, Application Deployment Plan	Jan 2019	GDOT
5	RSU Testing Summary	Jan 2019	GDOT
6	Executive Order 572	Oct 2016	MassDOT
7	Maryland Transportation Authority Strategic Plan for Connected and Automated Vehicles (CAV Plan)	Oct 2018	MDOT
8	Connected Vehicle Pilot Deployment Program	Jan 2021	USDOT
9	Interactive Connected Vehicle Deployment Map	Jul 2021	USDOT
10	AV Test Initiative	Jul 2021	NHTSA
11	Connected Roadway Classification System Development	Feb 2020	Texas A&M Transportation Institute
	Platooning Commercial Vehicles		
13	Vehicle Platooning Policy	Apr 2019	PennDOT
14	Authorizing Automated Vehicle Platooning: A Guide for State Legislators, 2019 Edition	Jul 2019	Competitive Enterprise Institute
15	Analysis of the operational and environmental benefits of truck platooning in freight transport: the case study of Luís Simões	May 2017	Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
16	ITS Deployment evaluation Executive Briefing – Truck Platooning	Jan 2016	USDOT
17	A Brief History of Truck Platooning	Jul 2016	Quick Transport Solutions Inc.
18	Truck Platooning Market - Growth, Trends, Covid-19 Impact, And Forecasts (2021 - 2026)	Jan 2021	Mordor Intelligence
19	U.S. States Are Allowing Automated Follower Truck Platooning While the Swedes May Lead in Europe	May 2020	Forbes
20	Truck Platooning Timeline Through 2030	May 2015	Next Big Future
	Personal Delivery Device		
21, 23, 26, 27	The Top Ten Autonomous Delivery Solutions of 2018	Jun 2018	Robotics Tomorrow
28	DHL Drone Delivery and Parcelcopter Technology	Oct2018	DHL
24, 25	8 Robots Racing to Win the Delivery Wars Of 2019	Jan 2019	Fastcompany
22, 31	Summary Report: Public Perception of Delivery Robots in the United States	Apr 2018	USPS
29	The Future of Delivery is Self-Driving	Unknown	Dominos
30	Domino's® Tests Autonomous Delivery with Nuro in Houston	Apr 2021	Dominos

Reference Footnote #	Title	Date Published/ Last Updated	Agency/ Source
	Connected Transit		
32	Automated And Connected Vehicle (AV/CV) Test Bed to Improve Transit, Bicycle, And Pedestrian Safety: Technical Report	Feb 2017	Texas A&M Transportation Institute
33	Intelligent Transportation Systems Deployment: Findings from the 2019 Connected Vehicle and Automated Vehicle Survey	Jun 2020	USDOT
34	Applications Of Connected Vehicle Infrastructure Technologies to Enhance Transit Service Efficiency and Safety	Sep 2016	Virginia Tech Transportation Institute (VTTI), University of Virginia (UVA) Center for Transportation Studies, and Morgan State University (MSU)
35	Multimodal Intelligent Traffic Signal System (MMITSS) Prototyping and Field Testing	Jan 2015	USDOT
	Connected and Automated Personal Use		
36	Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon	Apr 2020	Automated Vehicle Safety Consortium
37, 40	Planning For Connected and Automated Vehicles	Mar 2017	Center For Automotive Research, Public Sector Consultants
38, 42	Early Opportunities for AV Deployment in California Managed Lanes	Oct 2018	University of California, Berkley
39	AASHTO SPaT Challenge Webinar	Sep 2016	AASHTO
41	Automated Vehicles 3.0: Preparing for The Future of Transportation	Oct 2018	Akin Gump Strauss Hauer & Feld LLP
43, 44	Minnesota Governor's Council on Connected & Automated Vehicles	Feb 2021	MnDOT
45	Are We Ready to Embrace Connected and Self-Driving Vehicles? A Case Study of Texans	Nov 2016	University of Texas at Austin
46	Assessing Public Opinions of And Interest in New Vehicle Technologies: An Austin Perspective	Jun 2016	University of Texas at Austin
47	America THINKS: Sharing the Road with Autonomous Vehicles - 2019	Jul 2019	HNTB
12	Hard Breaking Event Dataset for I-35, TX	Dec 2020	Purdue University

Reference Footnote #	Title	Date Published/ Last Updated	Agency/ Source
	Production Passenger Vehicles with Vehicle-To-Infrastructure Connectivity		
48,51	What Is Vehicle-To-Infrastructure (V2i) Communication and Why Do We Need It?	Jan 2021	3M
49, 57, 58	Vehicle-To-Infrastructure Technologies Expected to Offer Benefits, But Deployment Challenges Exist	Sep 2015	GAO
50	Ten ways autonomous driving could redefine the automotive world	Jun 2015	McKinsey & Company
52, 53	What is Vehicle-to-Infrastructure Technology?	Jan 2019	RGBSI
54	What You Should Know About Vehicle-to-Infrastructure Communication	Oct 2020	Azuga
55	ITS Development Evaluation Executive Briefing: Connected Vehicle Pilot Deployment Program	Jun 2018	USDOT
56	Ford commits to deploy C-V2X technology on all new vehicles in the US beginning in 2022	Jan 2019	IEEE Connected and Autonomous Vehicles (VTS)
59	Are We Ready to Embrace Connected and Self-Driving Vehicles? A Case Study of Texans	Nov 2016	University of Texas at Austin

APPENDIX B: USE CASE POLL RESULTS AND SCORING METRICS

POLL RESULTS

Three focus groups were held between June 28 – 30, 2021 with District Traffic Engineers, Central Office staff, and staff of local municipalities and regional planning organizations. Following the description of each use case, participants were asked to rank each use case based on the participant's "perception of the influence of each in your future work.

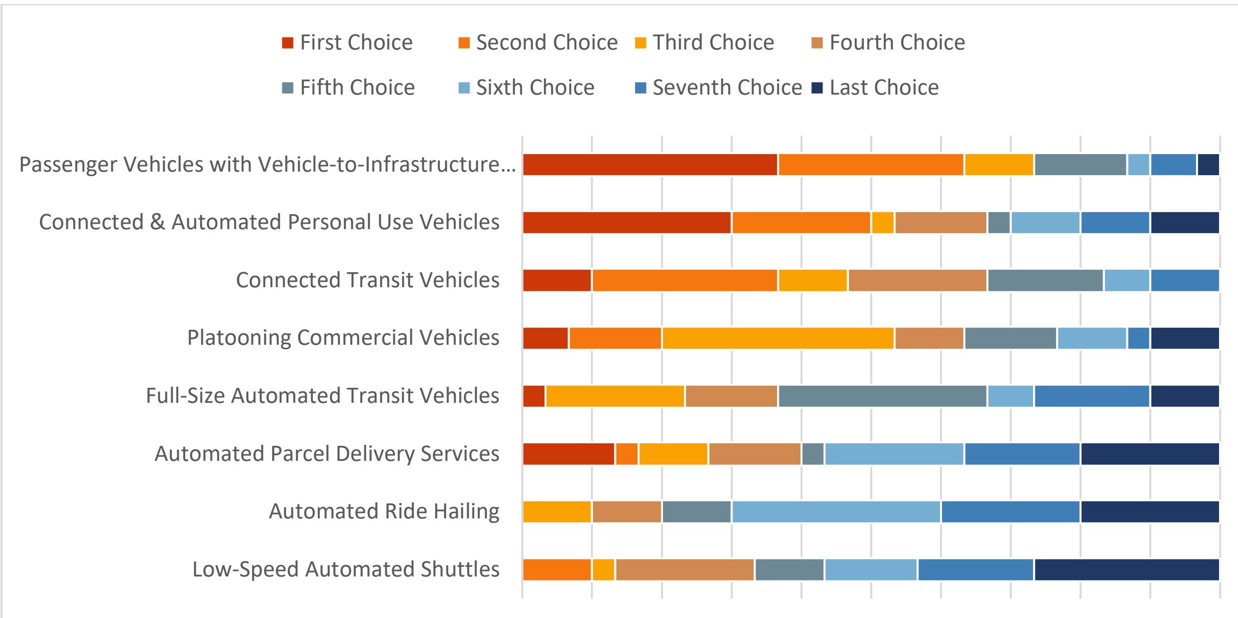

Figure 4: Combined Focus Group Poll Results

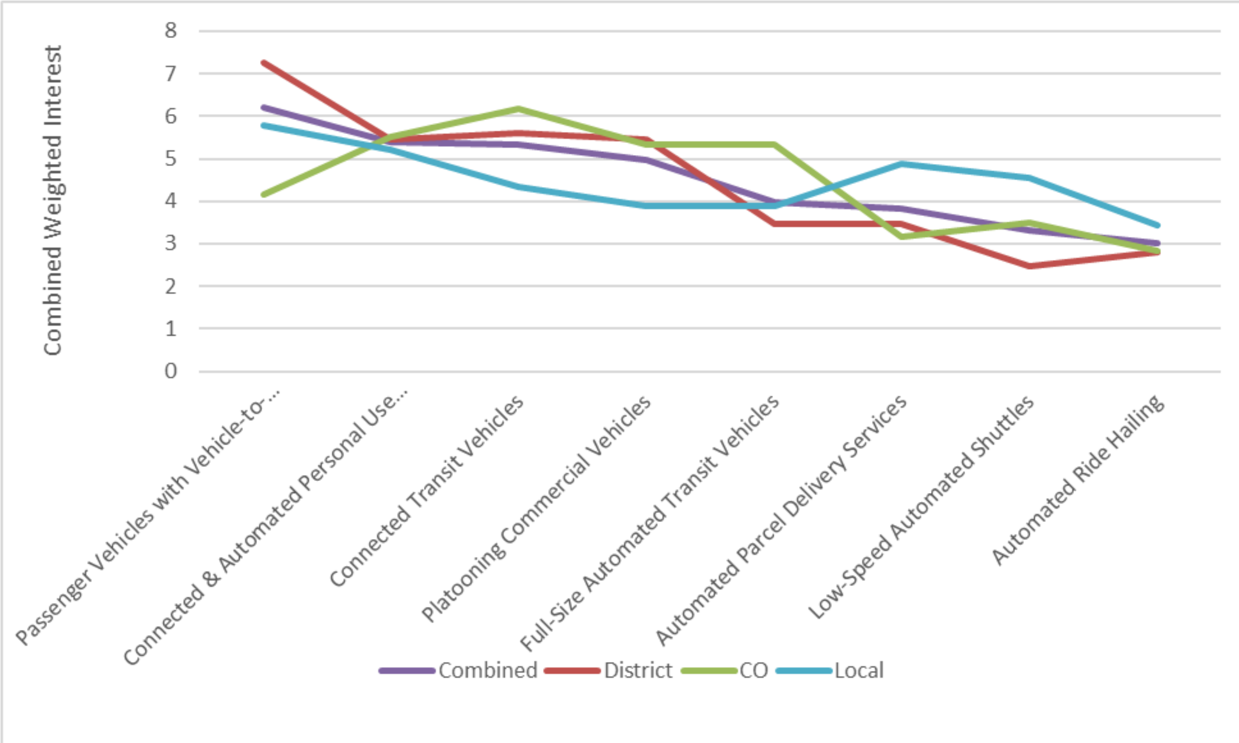

Figure 5: Rankings by Staff Type

SCORING METRICS

Table 2. Use Case Evaluation Criteria

CATEGORY	*RANKING OF 5*	*RANKING OF 1*
MARKET DEPLOYMENT	near-term	long-term
NEED FOR AGENCY RESOURCE INVESTMENT	agency investment will drive use case adoption	private industry will drive use case development and adoption
POTENTIAL PENNDOT IMPACT	PennDOT has the primary responsibility and authority to accelerate deployment through investments/support	PennDOT does not have the responsibility or authority to accelerate deployment through investments/support
DATA AVAILABLE FOR METHODOLOGY	data is readily available for public agency self-evaluation of deployments	data is not available for self-evaluation of deployments
CAV STRATEGIC PLAN ALIGNMENT	strong alignment	no alignment

Table 3. Use Case Evaluation Matrix Results

Use Case	*Market Deployment Timeline*	*Need for Agency Resource Investment*	*Potential PennDOT Impact*	*Data Available for Methodology*	*CAV Strategic Plan Alignment*	*Average Score*
Connected Use Cases						
*I2V Information Systems***	4	5	5	4	3	4.2
*ATMS**	5	5	5	3	3	4.2
*V2I Transit***	5	5	3	3	3	3.8
I2V Safety	2	5	5	3	3	3.6
I2V Messaging SPAT	4	5	3	3	3	3.6
I2V Ped/Bike/Micro	4	5	3	2	3	3.4
PMS	5	5	1	2	2	3
V2I Freight	4	2	2	2	2	2.4
V2I Passenger Vehicles	3	2	2	1	3	2.2
V2I Bike/Peds/Micromobility	1	1	1	1	2	1.2
Automated Use Cases						
*Level 4 Personal Use***	2	5	5	2	4	3.6
*LSAS***	5	4	3	2	3	3.4
*Automated Trucking**	3	3	3	3	3	3
*Level 2 Personal Use**	5	2	2	2	4	3
*Personal Delivery Device**	5	3	2	3	2	3
Automated Transit	2	5	1	3	4	3
Platooning Trucking	4	1	1	5	4	3
Automated Ride Hailing	3	1	1	2	2	1.8

*Recommended Use Case
**Excluded from Recommendations

OPEN ENDED QUESTION RESPONSES

Following the poll, participants were asked open ended questions. Some questions were asked of only one or two groups given the nature of their work. The summary of the questions is below.

ADDITIONAL USE CASES & EXPERIENCES WITH POLLED USE CASES

All three focus groups were asked if there were additional use cases, beyond the eight presented, which had either been piloted or launched in their areas, or which they had been approached about by private companies. The following additional use cases were identified:

- Automated sidewalk maintenance
- Automated sidewalk snow removal
- Automated pavement marking
- Truck-mounted attenuators

Participants also used this discussion question to provide feedback on their experiences with the use cases discussed during the polling portion of the focus group.

Local

Local agency representatives noted knowledge of use cases similar to personal delivery devices that could be used for sidewalk maintenance and clearing snow. They had also been approached by companies regarding automated ride hailing and automated shuttles.

Regarding polled use cases, agencies noted the low speed of LSAS and voiced concern the vehicles would travel too slowly to operate on the main roadways in their jurisdictions.

District

District representatives raised the use cases of automated line painting operation, truck-mounted attenuators able to autonomously move within a work zone, and automated shuttle buses, all of which were discussed.

One district noted that this Fall, an airport shuttle retrofitted with an automated driving system and a safety driver will be deployed at the Philadelphia airport. Districts also indicated a desire for projects to incorporate connected transit, although none had direct experience with the use case.

Central Office

A Central Office participant indicated the desire for connected transit to include driver assistance and pedestrian detection or warning systems as early-action steps or gateways to bigger connected technologies.

IMPORTANT CONSIDERATIONS FROM A PLANNING PERSPECTIVE

The local agency group was asked which of the use cases was most important to consider when planning. Responses to this question focused more on broad considerations for planning for transformational technologies in general, rather than specific use cases. Overall, participants shared the following considerations:

- Coordinating across multiple agencies
- Avoiding using company-provided timeline and benefit projections
- Challenge of maintaining existing infrastructure in addition to adding new infrastructure
- Ensuring technology enhances mobility equitably between and within Districts

Local

Local staff identified the following considerations when planning for technology services: coordination, overcoming skepticism, and impact on VMT.

1. Coordination was discussed as the primary problem from a planning perspective. For example, it was difficult to bring everybody together across a multi-state region for the planning of a LSAS in Philadelphia Navy Yard.
2. Local staff also expressed skepticism that technologies will ever develop, with concern that promised benefit will fall short, or potential disbenefits will be greater than anticipated.
3. There is interest to understand what an influx of CAVs means to an overtaxed road infrastructure system that is already challenging to keep up with, such as in major, growing suburbs.

District

While District staff where not asked about planning considerations, there was discussion in the focus group about equity. It was important to District representatives that Department use of any technology is distributed equitably and effectively across the Commonwealth.

Central Office

While Central Office staff were not asked about planning considerations, participants expressed interest in leveraging technologies to help underserved communities, with an emphasis on how to enhance mobility options for underserved communities and less emphasis on targeting mobility deserts where there are limited options.

CONCERN AND INTEREST FOR USE CASES

Local and District focus groups were asked about regional level of support or interest for CAV use cases. Responses included discussion of use cases where participants felt interest was strongest as well as the use cases where concern was strongest. District participants tended to voice concern of transformational technologies in general rather than for specific use cases.

Overall, the interest was strongest for the following use cases:

- Personal delivery devices
- CAV personal vehicles

Concern was strongest for the following use cases:

- Automated line painting

Local

Local agencies expressed a primary interest in personal delivery devices, in large part due to Pennsylvania legislation that was passed, where other technologies seem distant and nebulous. There was recognition for need to think about things like curb management a little more. Participants representing suburban counties indicated interest in the following four use cases, in descending order: CAV personal vehicles, personal delivery device, commercial platooning, and automated transit.

District

In general, District staff expressed concern about liabilities and needs to serve CAVs as compared to all existing needs, as well as concern that the benefits of CAVs may not outweigh the costs. These impacts could vary by region. For example, Tri-County is particularly well suited for platooning commercial vehicles because the MPO is at the intersection of I-81, I-83, and the Turnpike.

The general sentiment of one district was that private sector technology has not proved the safety, transit supplementation, and first-/last-mile improvement benefits they are promising. Private industry has provided economic benefits to the region and there is economic support for this technology, but the biggest public automation concern is job loss. Further, District staff indicated citizens are keyed into electric vehicles because they see commercials and vehicles on the road, but they do not see automated or connected vehicles, or do not think of the vehicles we have as connected.

During discussion of the automated line paining, some attendees voiced concerns that it would be extremely difficult to automate the procedure.

DATA SOURCES FOR TARGETING USE CASE INFRASTRUCTURE NEEDS

All three focus groups were asked what data sources, if any, they had used to help target infrastructure needs of CAV use cases. Participants also used this time to discuss data sources to which they would like to have access including:

- Traffic signal equipment and infrastructure
- Sidewalk usage
- CAV-related crashes
- System performance data

Currently used data sources included:

- Safety-based data
- Congestion-based data

Local

Local Agencies said that they are having data sharing conversations with the private industry. For example, as part of a planned delivery device pilot, local agencies are discussing how providers could supply real-time congestion or delay data in the future.

With respect to additional data needs, participants identified

- Inventorying traffic signal equipment age to evaluate connected capabilities.
- Development of plans and regulations with respect to sidewalk and pedestrian data usage.
- Crashes and interactions between CAV's and other road users, including pedestrians.

Agencies noted the challenge of crash data regarding automated delivery devices, recently classified by legislation as "pedestrians". Agencies are trying to identify how crashes and safety issues will be measured (such as crashes between a sidewalk delivery vehicle and a pedestrian), because pedestrian-on-pedestrian crashes normally would not be reported.

An effort two years ago examining V2I, and communications technology was discussed, which studied locations across the six District 8 Metropolitan Planning Organizations (MPO). A prioritization system was developed in this effort based on safety, congestion, and a range of other issues, with a focus on the non-Interstate system.

District

District representatives indicated they receive requests from private companies for traffic signal data. However, because signals are municipality-owned, the Districts have no rights to share signal data. This creates challenges for private companies who do not have resources to reach out to scores of municipalities.

New agreements are being examined where co-ownership of signal data would allow Districts to share signal data with private companies. There seems to be inconsistency in data sharing, as Chief council pushed decisions to local municipalities that own data. The City of Philadelphia and District 6 were both approached by a private company about sharing signal data, but the district had to coordinate through the municipality rather than directly with the company.

Central Office

Central Office representatives noted research by Purdue University analyzing Wejo data to monitor system performance. They are looking to pilot a radar system project in D3, providing cloud-based data that can be used in applications. In considering which data to prioritize access to, participants highlighted the struggle to make sure they are getting the best return on their investment and the importance of asking the question "What problems are you trying to solve?"

APPENDIX C: RUBRIC INSTRUCTIONS

USE CASE #1: ADVANCED DRIVER-ASSISTANCE SYSTEMS

SCORING DESCRIPTION & OVERVIEW

Partial automation is achieved by SAE Level 2 driver assistance systems, which are currently available and becoming standard equipment on a growing number of light vehicles. The methodology evaluates this use case in the **regional context**. Due to the variety of ADAS technologies currently available, the score is broken into two components to match specific ADAS technology solutions to the identified problems and roadway characteristics in a region. The lateral applications component evaluates roadways for potential of strategies such as lane keeping and lane departure warnings. The longitudinal component evaluates roadways for potential of applications such as traffic jam assist or forward collision warning in congestion, foggy conditions, or high-speed approach intersections.

METHODOLOGY

- **Step 1:** Define region for consideration in the assessment. The ideal region is likely a county or area of similar size but may also be a District, city, or other defined area for which assistance is sought. It should include the full extent of potential deployment limits.
- **Step 2:** Calculate the total length of roadway in the region in miles. This should include interstates and major state highways but may also include local roads. This likely will not include residential roads. Each direction of roadway should be counted separately.
- **Step 3:** Evaluate Applicability of Lateral ADAS Applications
  - **Step 3A***:* Is there a safety issue in the region?
    - ***Score Type***: Database Determined
    - ***Database Source:*** Pennsylvania Crash Information Tool
      - Filters: "Single Vehicle Run Off Road" crash event and Head On/Opposite Direction Sideswipe (Non-Intersection)
    - ***Rubric Description:*** Select a score, 1 through 5, based on the five-year average of run off road crashes per year per mile of roadway as defined in Step 2.
      - The rubric is based on a statewide average of 51,530 run off road crashes and non-intersection head on/opposite direction sideswipes per year between 2016-2020 and 58,385 total miles of state and county directional roadway for a rate of 0.9 crashes per year per mile.
    - ***Rationale:*** Rates above the statewide average score higher in the rubric (4-5) to indicate where ADAS technologies may be most beneficial for safety improvements, while crash rates below score lower (1-2). If score is one (i.e., no run-off the road crashes), lateral ADAS technologies is likely to provide less safety value-add.
    - ***Next Step:*** If score is one, proceed to Step 4. If score is 2 or greater, proceed to Step 3B.
  - **Step 3B***:* How recently have roads been resurfaced in the region?

- ***Score Type:*** Database Determined
- ***Database Source:*** PennDOT One Map
    - Layers: Roadway – Pavement – Pavement History
    - Filters: "Layer Types" and "Layer Year" to include only asphalt or concrete roadways resurfaced in the past 10 or 25 years, respectively.
- ***Rubric Description:*** Select a score, 1 through 5, weighted average of the percentage of the asphalt roadways resurfaced in the last 10 years and percentage of concrete roadways resurfaced in the last 25 years.
- ***Rationale:*** If score is 3 or above, resurfacing of roadways could create more favorable conditions for ADAS to be more effective. If score is 2 or below, ADAS technologies likely already can operate effectively on the roadway and resurfacing provides less value-add.
- ***Next Step:*** Proceed to Step 3C.

- **Step 3C***:* What is the quality of road markings in the region?
    - ***Score Type:*** Self-Scoring
    - ***Potential Data Sources:*** Pavement Marking Asset Management System (provided by local PennDOT District) or local knowledge
    - ***Rubric Description:*** Select a score, 1 through 5, based on self-scoring estimation of pavement quality and prevalence of waterborne versus durable paint.
    - ***Rationale:*** If score is 3 or above, the roadway has poor quality road markings or high use of waterborne paint that requires frequent maintenance. Restriping of roadways and adding durable paint can create more favorable conditions for ADAS technologies to be more effective. If score is 2 or below, ADAS technologies likely already can operate effectively on the roadway and improving road markings provides less value-add.
    - ***Next Step:*** Proceed to Step 3D.
- **Step 3D***:* Does the region have upcoming projects that could be leveraged?
    - ***Score Type:*** Database Determined and Self-Scoring
    - ***Database source:*** PennDOT One Map and Regional Operations Plan (ROP)
        - One Map Layers: MPMS – Projects - In development and future development
        - One Map Filters: "Improvement Type" to include corridor safety improvement, guiderail improvements, new roadway, pavement preservation, resurfacing, reflective pavement markers.
        - Regional Operations Plans (select based on location of region)
            - Western Region
            - Central Region
            - Eastern Region
            - Southeastern Region
    - ***Rubric Description:*** Select a score, 1 through 5, based on the number of projects with the above improvement types flagged for in development or future development per mile. Use total miles of roadway in region as defined in Step 2 as denominator and number of projects in the MPMS plus

relevant projects identified in ROP for planned development in as numerator to calculate the number of projects per mile of roadway.

- The rubric is based on 3,100 statewide projects flagged for these improvements as in development or future development and 58,385 miles of statewide roadway for an average rate of .05 projects per mile.

- ***Rationale:*** If score is 3 or above, there are more opportunities to add roadway improvements to planned projects to create more favorable conditions for lateral ADAS technologies. If score is 2 or below, there are few planned projects in which improvements to enable ADAS technologies could be made.
- ***Next Step:*** Proceed to Step 3E.

- **Step 3E***:* What is the average age of vehicles in the region?
  - ***Score Type:*** Database Determined
  - ***Database source:*** National Household Travel Survey
    - Analysis Variable: Vehicle age (years)
    - Row Variable: HH_CBSA - Core Based Statistical Area (CBSA) FIPS code for the respondent's home address
  - ***Rubric Description:*** Select a score, 1 through 5, based on the average age of vehicle for the MSA of more than 1 million people that contains the region in the assessment (Pittsburgh, Philadelphia-Camden-Wilmington, or New York-Newark-Jersey City). If region does not fall into one of the three large MSAs, use the average value for *Suppressed, in an MSA of less than 1 million*.
  - ***Rationale:*** Higher scores indicate newer vehicles, which may indicate a greater likelihood ADAS is available on vehicles. However, ADAS technologies, even for newer vehicles, does vary by vehicle manufacturer and model. See scoring description and overview for caveats.
  - ***Next Step:*** Proceed to Step 4.

- **Step 4:** Evaluate Applicability of Longitudinal ADAS Applications
  - **Step 4A***:* Is there a safety issue in the region?
    - ***Score Type:*** Database Determined
    - ***Database Source:*** Pennsylvania Crash Information Tool
      - Filters: "Rear End" and "Back-Up" crash event filters)
    - ***Rubric Description:*** Select a score, 1 through 5, based on the five-year average of rear end and back up crashes per year per mile of roadway as defined in Step 2.
      - The rubric is based on a statewide average of 27,000 rear end and back-up crashes per year between 2016-2020 and 58,385 total miles of state and county directional roadway for a rate of 0.5 crashes per year per mile.
    - ***Rationale:*** Rates above the statewide average score higher in the rubric (4-5) to indicate where ADAS technologies could be most beneficial, while crash rates below score lower (1-2). If there are no rear end or back-up crashes, longitudinal ADAS technologies provides less safety value-add.
    - ***Next Step:*** If score is one, assessment is complete. Total final score. If score is 2 or greater, proceed to Step 4B.

- **Step 4B***:* Is there congestion in the region?
  - ***Score Type:*** Database Determined
  - ***Database Source:*** PennDOT One Map
    - Layers: TSMO - TomTom Travel Time Ratio >2 Layer
    - Filters: TTR_PEAK >2 filter
  - ***Rubric Description:*** Select a score, 1 through 5, based on the percentage of roadway in region with TTR >2. Use total miles of roadway in region as defined in Step 2 as denominator and number of miles with TTR >2 in OneMap as numerator to calculate the percentage.
    - The rubric is based on 58,385 total miles of state and county directional roadway with 2,625 miles statewide with TTR>2 for a statewide rate of 4%.
  - ***Rationale:*** If score is 3 or above, significant congestion in the corridor may be an indicator that longitudinal ADAS technologies will be useful, such as traffic jam assist or forward collision warning. If score is 2 or below, longitudinal ADAS applications provide less safety value-add.
  - ***Next Step:*** Proceed to Step 4C.
- **Step 4C**: Are there traffic bottlenecks in the region?
  - ***Score Type:*** Database Determined
  - ***Database Source:*** PennDOT One Map
    - Layers: TSMO - Major Traffic Bottlenecks – 2018
  - ***Rubric Description:*** Select a score, 1 through 5, based on the highest (worst) ranked bottleneck in region. Use "RANKING" variable to identify highest ranked bottleneck in the region (lower number = more severe bottleneck).
  - ***Rationale:*** If score is 3 or above, significant bottlenecks in the corridor may be an indicator that longitudinal ADAS technologies may help to avoid back-up crashes, such as traffic jam assist or forward collision warning. If score is 2 or below, longitudinal ADAS applications provide less safety value-add.
  - ***Next Step:*** Proceed to Step 4D.
- **Step 4D**: Are there known areas in the region with recurring foggy conditions?
  - ***Score Type:*** Self-Scoring
  - ***Potential Data Sources:*** Sign Asset Management System or local knowledge
  - ***Rubric Description:*** Select a score, 1 through 5, based on self-scoring estimation of number of fog-ahead signs indicating known foggy areas in the region.
  - ***Rationale:*** If score is 3 or above, high numbers of foggy areas/signs may indicate problem areas where longitudinal ADAS applications could help to avoid rear-end and back-up crashes. If score is 2 or below, longitudinal ADAS applications provide less safety value-add.
  - ***Next Step:*** Proceed to Step 4E.
- **Step 4E**: Does the region have high-speed approaches to signals?
  - ***Score Type:*** Self-Scoring
  - ***Database Source:*** Sign Asset Management System or local knowledge

- ***Rubric Description:*** Select a score, 1 through 5, based on self-scoring estimation of number of intersections with signal-ahead flashing signs indicating high speed and/or low visibility approach intersections in the region.
- ***Rationale:*** If score is 3 or above, high numbers of signal ahead flashing signs may indicate intersections where longitudinal ADAS applications could help to avoid rear-end and back-up crashes. If score is 2 or below, longitudinal ADAS applications provide less value-add.
- ***Next Step:*** Proceed to Step 4F.

- **Step 4F**: Does the region have upcoming projects that could be leveraged?
  - ***Score Type:*** Database Determined
  - ***Database source:*** PennDOT One Map and Regional Operations Plan
    - Layers: MPMS – Projects - In development and future development
    - Filters: "Improvement Type" to include corridor safety improvement, lighting, VMS.
    - Regional Operations Plans (select based on location of region)
      - Western Region
      - Central Region
      - Eastern Region
      - Southeastern Region
  - ***Rubric Description:*** Select a score, 1 through 5, based on the number of projects with the above improvement types flagged for in development or future development per mile. Use total miles of roadway in region as defined in Step 2 as denominator and number of projects in the MPMS plus the number of relevant projects identified in the ROP for planned development in as numerator to calculate the number of projects per mile of roadway.
    - The rubric is based on 145 statewide projects flagged for these improvements as in development or future development with 58,385 miles statewide roadways for a rate of .002 projects per mile as average.
  - ***Rationale:*** If score is 3 or above, there are more opportunities to add roadway improvements to planned projects to create more favorable conditions for longitudinal ADAS technologies. If score is 2 or below, there are few planned projects in which improvements to enable ADAS technologies could be made.
  - ***Next Step:*** Proceed to Step 4G.

- **Step 4G***:* What is the average age of vehicles in the region?
  - ***Score Type:*** Database Determined
  - ***Database source:*** National Household Travel Survey
    - Analysis Variable: Vehicle age (years)
    - Row Variable: HH_CBSA - Core Based Statistical Area FIPS code for the respondent's home address
  - ***Rubric Description:*** Select a score, 1 through 5, based on the average age of vehicle for the MSA of more than 1 million people that contains the region in the assessment (Pittsburgh, Philadelphia-Camden-Wilmington, or New York-Newark-Jersey City). If region does not fall into one of the three large MSAs, use the average value for *Suppressed, in an MSA of less than 1 million*.

- ***Rationale:*** Higher scores indicate newer vehicles, which may indicate a greater likelihood ADAS is available on vehicles. However, ADAS technologies, even for newer vehicles, does vary by vehicle manufacturer and model. See scoring description and overview for caveats.
- ***Next Step:*** Assessment is complete. Total final score.

SCORE EVALUATION

For ADAS, a region score can be evaluated as a combined lateral and longitudinal score. Alternatively, regions may be considered for specific technologies or support if a high score exists in only one category.

- A higher lateral direction applications score indicates where systems like lane departure warning or roadway departure warning may be a useful safety countermeasure if installed and engaged on the vehicle. PennDOT may consider infrastructure or coordination with local agencies in the region to improve engagement rates of ADAS-equipped vehicles.
- A higher longitudinal direction applications score indicates where technologies such as traffic jam assist applications may be a useful safety countermeasure against congestion, rear-end crashes, recurring poor weather, or high-speed approaches to intersections. PennDOT may consider infrastructure, coordination, or policy support to encourage deployment in the region.
- A lower score in either the lateral or longitudinal applications scores may indicate areas where ADAS technology could be or are already deployed and operating but does not solve a specific problem for PennDOT action or investment.

USE CASE #2: AUTOMATED TRUCKING

SCORING DESCRIPTION & OVERVIEW

As time progresses, it can be expected that the fleets will move from platooning toward full automation on limited-access highways. Performance to achieve full automation will need to be supported by PennDOT. The scoring methodology seeks to identify roadways, in a **corridor context,** with high freight volume, low congestion, favorable weather conditions, and easy access to truck generating land-uses where these investments can be made in areas where truck automation is most likely to be adopted. PennDOT may also explore partnerships with industry in high-scoring regions to facilitate adoption of automated trucking.

METHODOLOGY

- **Step 1:** Define corridor for consideration in the assessment. It should be a contiguous stretch of pavement and include the full extent of potential deployment limits. The extents of the ideal corridor should be an interchange (as opposed to mid-segment) and may include tens or hundreds of miles. The corridor may include multiple roads.
- **Step 2**: Calculate the total length of roadway in the corridor in miles. Each direction of roadway should be counted separately.
- **Step 3:** Evaluate Corridor Characteristics
  - **Step 3A:** Is the corridor in a truck route?
    - ***Score Type:*** Database Determined
    - ***Database Source:*** PennDOT One Map
      - Layers: AADTT Thresholds
    - ***Rubric Description:*** Select a score, 1 through 5, based on the weighted average AADTT across the corridor, weighted by distance. For all segments in the corridor, assign the score you'd get for that segment (e.g., 3 for AADTT between 100 and 300), multiply by the distance, then sum with all other segments and divide by number of segments to calculate the weighted average.
    - ***Rationale:*** If score is 1, the corridor is unlikely to be a candidate for automated trucking due to low truck traffic (weight limits, low bridges, etc.). Industry is likely to target areas with high freight volumes for early deployment of automated trucking.
    - ***Next Step:*** If score is 2 or above, proceed to Step 3B. If score is 1, assessment is complete. Total final score.
  - **Step 3B:** What are the roadway characteristics of the corridor?
    - ***Score Type:*** Database Determined
    - ***Database Source:*** PennDOT One Map
      - Layers: Roadway segments - Administrative Info - Functional Classification (collectors, arterials, and interstates)
    - ***Rubric Description:*** Select a score, 3 through 5, based on the plurality of roadway miles classification. For the denominator, use the total miles of roadway in the corridor defined in Step 2. For the numerators, use the number of miles of roadway for each classification to calculate and identify which classification has the highest percentage of roadway miles.

    - ***Rationale:*** Testing or deployment of new technologies with larger vehicles is unlikely in residential areas. Collectors, arterials, and state highways (short, repetitive routes from warehouse to warehouse) and higher classifications of roads such as interstates are more likely deployment locations for automated trucking.
    - ***Next Step:*** Proceed to Step 4.

- **Step 4:** Is there truck congestion on the corridor?
  - ***Score Type:*** Database Determined
  - ***Database Source:*** PennDOT One Map
    - Layers: TSMO - Truck Bottleneck Rankings 2019
    - ***Rubric Description:*** Select a score, 1 through 5, based on the highest (worst) ranked truck bottleneck segment on the corridor. Use "RANKING_BY_ABR" variable to identify highest ranked bottleneck on the corridor (lower number = more severe bottleneck).
  - ***Rationale:*** The benefits of current and emerging technology are best suited for trips of longer duration without challenging congestion. If score is 2 or below, the corridor is unlikely to be a candidate for automated trucking due to congestion. Intelligent Transportation Systems are likely more effective for these congested corridors.
  - ***Next Step:*** Proceed to Step 5.
- **Step 5:** Are there hotspots of truck generating land-uses along the corridor as potential origins and destinations?
  - ***Score Type:*** Self-Scoring
  - ***Potential Data Sources:*** Department of Community and Economic Development or local knowledge.
    - Layers: Businesses – Industries - "General Freight Trucking" and "Specialized Freight Trucking"
  - ***Rubric Description:*** Select a score, 1 through 5, based on a self-scoring estimation of ease of access to truck origins and destinations along corridor. The DCED database provides a starting point for identifying potential industry locations along the corridor, from no locations (low score) to numerous locations and industry partners already identified (high score).
  - ***Rationale:*** Higher scores indicate the corridor provides easy access to clusters of potential origins and destinations and may be a good candidate for partnerships and automated trucking deployments.
  - ***Next Step:*** Proceed to Step 6.
- **Step 6***:* What is the quality of road markings in the region?
  - ***Score Type:*** Self-Scoring
  - ***Potential Data Sources:*** Pavement Marking Asset Management System or local knowledge
  - ***Rubric Description:*** Select a score, 1 through 5, based on self-scoring estimation of pavement quality and prevalence of waterborne versus durable paint.
  - ***Rationale:*** A higher score indicates the roadway has poor-quality road markings or high use of waterborne paint that requires frequent maintenance. A high score indicates a PennDOT opportunity to restripe roadways and add durable paint to create more favorable conditions for automated trucking technologies to be more effective. A lower score indicates the pavement markings may already be suitable for the technology, requiring less intervention from PennDOT.

  - ***Next Step:*** Proceed to Step 7.
- **Step 7**: Does the corridor have recurrent issues with fog?
  - ***Score Type:*** Self-Scoring
  - ***Potential Data Sources:*** Sign Asset Management System or local knowledge
  - ***Rubric Description:*** Select a score, 1 through 5, based on self-scoring estimation of number of fog-ahead signs indicating known foggy areas in the region.
  - ***Rationale:*** A lower score indicates the corridor is unlikely to be an early deployer of automated trucking technologies. Current technologies are better suited for favorable weather conditions.
  - ***Next Step:*** Proceed to Step 8.
- **Step 8**: Does the corridor have recurrent issues with snowfall?
  - ***Score Type:*** Database Determined
  - ***Database source:*** National Weather Service (Total Average Annual Snowfall 1991-2020) or local knowledge
  - ***Rubric Description:*** Select a score, 1 through 5, based on an estimation of number of inches of snowfall per year on corridor
  - ***Rationale:*** A lower score indicates the corridor is unlikely to be an early deployer of automated trucking technologies due to unfavorable weather conditions.
  - ***Next Step:*** Assessment is complete. Total final score.

SCORE EVALUATION

For automated trucking, a total score can be compared directly between corridors. Higher scores indicate corridors most favorable to automated trucking, including an existing freight route, low congestion, potential nearby industries, and favorable weather. If these characteristics exist, Truck Automation is more likely and PennDOT may consider prioritizing enhanced pavement markings or partnerships with freight providers.

USE CASE #3: PERSONAL DELIVERY DEVICE

SCORING DESCRIPTION & OVERVIEW

PennDOT can play a vital role in supporting local agencies to plan, monitor, and enforce the emerging applications of personal delivery devices. The methodology evaluates this use case in the **regional context**. The methodology aims to identify regions with favorable land-uses environments that are walkable with short distances between signalized crossings and limited potential conflicts with vehicles or high-speed roadways. Scores for this use case may indicate regions where PDD may be initially deployed, and where PennDOT can provide targeted guidance on a variety of challenges regional leaders may face, including roadway design, data sharing agreements, and reporting and enforcement of violations, crashes, or conflicts between these devices and other pedestrians or bicyclists on the sidewalk.

METHODOLOGY

- **Step 1:** Define region for consideration in the assessment. The ideal region for assessment is likely a neighborhood or district within a city (including education campuses or business parks) but may also be a District, county, city, or other defined area for which PennDOT assistance is sought or deployment is being considered. It should include the full extent of potential PDD deployment limits but avoid extraneous areas likely outside of the deployment limits.
- **Step 2:** Is the region in an urbanized area?
  - ***Score Type:*** Database Determined
  - ***Database Source:*** PennDOT One Map
    - Layer: Boundaries - 2010 Urbanized Boundaries
  - ***Rubric Description:*** Select a score, 0 or 1, based on the identification of region according to 2010 urbanized boundaries The rubric is a binary score if the region is/is not part of an urbanized area. If the area is not part of an urbanized area but encompasses a post-secondary educational campus, select a score of 1.
  - ***Rationale:*** If the region is not part of an urbanized area (0 score), personal delivery device deployments are unlikely due to low delivery density.
  - ***Next Step:*** If score is one, proceed to question Step 3. If score is zero, assessment is complete. Total final score.
- **Step 3:** Does the region have favorable intersection control types?
  - ***Score Type:*** Self-Score
  - ***Potential Data Sources:*** Map or local knowledge
  - ***Rubric Description:*** Select a score, 1 to 5, based on the self-scoring estimation of the average distance between signalized crossings, including signalized mid-block crossings, with pedestrian recall across the main street.
  - ***Rationale:*** In general, frequent signalized crossings are favorable for PDD travel. Likewise, regions with limited vehicular access between buildings reduce PDD-vehicle conflicts and increase likelihood of deployment.
  - ***Next Step:*** Proceed to Step 4.
- **Step 4:** Is the region pedestrian friendly (speeds, ramp access, etc.)?

- *Score Type:* Database Determined
- *Database Source:* WalkScore
- *Rubric Description:* Select a score, from 1 to 5, based on the average WalkScore for region. The average can be calculated by entering each zip code within the region into WalkScore, summing the results, and dividing by the number of zip codes.
- *Rationale:* Higher scores indicate the region is already pedestrian friendly and may be an early deployment site for PDDs that rely on pedestrian-like facilities.
- *Next Step:* Proceed to Step 5.

- **Step 5:** Does the region have favorable land uses?
  - *Score Type:* Database Determined and Self-Score
  - *Database Source:* Department of Community and Economic Development or local knowledge/map
    - Layers: Map Layers – Post Secondary Education
  - *Rubric Description:* Conduct a count of campuses, central business districts, or mixed-use/business park environments in the region based on DCED database of post-secondary education campuses and local knowledge or map of Central Business Districts (CBDs), mixed-use developments, and business parks. The region is awarded five points per campus, four points per CBD, and three per mixed-use development or business park.
  - *Rationale:* PDD is likely to deploy in areas with high person-density where personal or business delivery is in demand.
  - *Next Step:* Assessment is complete. Total final score.

SCORE EVALUATION

To date, PDD technology use cases are limited to walkable urbanized areas, which may include campuses and dense central business districts or business parks with short trip distances and minimal unsignalized conflicts with vehicles. The devices are most reliable in existing pedestrians-friendly environments with low speeds and ramp access to sidewalks. For PDD, the total score can be evaluated directly across regions. A higher score may indicate one or more of these characteristics and opportunities for PennDOT to provide guidance to local agencies on deployment best practices or partner with private PDD companies in areas where they may target pilots or deployments.

WARNING: An artificially wide assessment region may provide an overly inflated value due to the scoring of Step 3. Selected region should be reviewed to ensure it represents a reasonable area for deployment.

USE CASE #4: INFRASTRUCTURE TO VEHICLE

SCORING DESCRIPTION & OVERVIEW

PennDOT is in a strong position to accelerate I2V connected vehicle applications of traveler information systems. The methodology evaluates this use case in the **corridor context**. Due to the variety of I2V applications currently available, the score is broken into four components to match specific technology solutions to the identified problems and roadway characteristics in a corridor. The safety applications component evaluates the corridor for higher-than-average crash rates and planned safety improvement projects as potential candidates for I2V safety applications. The congestion component evaluates the corridor for bottlenecks as potential candidates for I2V applications. The signals component evaluates capacity of signals in a corridor to communicate with PennDOT's network to transmit signal data to vehicles. The ITS devices component evaluates the likelihood to deploy given where ITS information infrastructure already exists.

METHODOLOGY

- **Step 1:** Define corridor for consideration in the assessment. It should be a contiguous stretch of pavement and include the full extent of potential project limits. The ideal corridors are complete segments, likely interchange to interchange for limited access roadways or intersection to intersection for other roadways. The corridor may include multiple roads.
- **Step 2:** Calculate the total length of roadway in the corridor in miles. Each direction of roadway should be counted separately.
- **Step 3:** Are there existing ITS devices on the corridor that provide information or feedback to motorists?
  - ***Score Type***: Database Determined
    - ***Database Source:*** PennDOT One Map
      - Layers: Dynamic Message Signs, Highway Advisory Beacons & Radios, RWIS Stations
  - ***Rubric Description:*** Select a score, 1 through 5, based on number of these types of ITS devices per mile in the corridor. Use the total number of devices on the corridor as the numerator, with the denominator the total miles of roadway in the corridor from Step 2.
  - ***Rationale:*** The rubric is based on a total of 1,070 devices statewide and 58,385 total miles of state and county directional roadway for a rate of 0.02 devices per mile. Rates above the statewide average score higher in the rubric (4-5) to indicate where I2V applications could be deployed and connected to existing to ITS devices, while rates below score lower (1-2).
  - ***Next Step:*** Proceed to Step 4.
- **Step 4:** Are there traffic bottlenecks on the corridor?
  - ***Score Type:*** Database Determined
  - ***Database Source:*** PennDOT One Map
    - Layers: TSMO - Major Traffic Bottlenecks – 2018
  - ***Rubric Description:*** Select a score, 1 through 5, based on the highest (worst) ranked bottleneck on the corridor. Use "RANKING" variable to identify highest ranking bottleneck on the corridor (lower number = more severe bottleneck).

- ***Rationale:*** If score is 3 or above, significant bottlenecks (higher rank = more severe bottleneck) in the corridor may be an indicator that I2V congestion applications (I2V situational awareness of downstream roadway conditions such as bottlenecks and construction) could be potentially deployed. If score is 2 or below, I2V congestion applications may provide less value-add.
- ***Next Step:*** Proceed to Step 5.

- **Step 5***:* Is there a safety issue in the region?
  - ***Score Type*****:** Database Determined
  - ***Database Source:*** Pennsylvania Crash Information Tool
    - Filters: Date Range: Most recent five-year period (e.g., January 2016 - December 2020)
  - ***Rubric Description:*** Select a score, 1 through 5, based on the five-year average of crashes per year per mile of roadway as defined in Step 2.
  - ***Rationale:*** The rubric is based on a statewide average of 123,280 crashes per year between 2016-2020 and 58,385 total miles of state and county directional roadway for a rate of 2.1 crashes per year per mile. Rates above the statewide average score higher in the rubric (4-5) to indicate where I2V safety technologies could be most beneficial, while crash rates below score lower (1-2). If there is a low crash rate, deployment of I2V safety technologies may provide fewer safety benefits.
  - ***Next Step:*** Proceed to Step 6.
- **Step 6:** Does the region have upcoming projects that could be leveraged?
  - ***Score Type:*** Database Determined
  - ***Database source:*** PennDOT One Map and Regional Operations Plan
    - Layers: MPMS – Projects - In development and future development
    - Filters: "Improvement Type" to include corridor safety improvement, intersection improvement, safety improvement, and VMS.
    - Regional Operations Plans (select based on location of region)
      - Western Region
      - Central Region
      - Eastern Region
      - Southeastern Region
  - ***Rubric Description:*** Select a score, 1 through 5, based number of projects with the above improvement types flagged for in development or future development per mile. Use total miles of roadway on the corridor as defined in Step 2 as denominator and number of projects in the MPMS plus the number of relevant projects identified in the ROP for planned development in as numerator to calculate the number of projects per mile of roadway.
  - ***Rationale:*** The rubric is based on 809 statewide projects flagged for these specific improvements as in development of future development with 58,385 miles of state and county directional roadway for a rate of 0.01 projects per mile as average. If score is 3 or above, there are more opportunities to add roadway improvements to planned projects to create more favorable conditions for I2V safety technologies. If score is 2 or below, there are few planned projects in which improvements to enable I2V technologies could be made, meaning any I2V deployment would need to be conducted under a new project.

  - ***Next Step:*** Proceed to Step 7.

- **Step 7:** Are signals in the corridor connected to the PennDOT network?
  - ***Score Type:*** Database Determined and Self-Score
  - ***Potential Data Sources:*** Traffic Signal Asset Management System
  - ***Rubric Description:*** Select a score, 1 through 5, based on the self-scoring estimation of the percent of signals on the corridor connected to PennDOT's network. TSAMS can provide the total number of signals on a corridor (denominator). The numerator will be a self-assessment estimation to calculate the percentage. If this question does not apply (e.g., interstate corridor analysis), enter N/A and score the I2V use case out of 20.
  - ***Rationale:*** If score is 3 or above, there are more signals connected to PennDOT's network providing the capability to remotely manage the information pushed out to vehicles. It would also provide the ability to do a central-based I2V solution using a third-party service if PennDOT does not have equipment deployed to transmit directly to vehicles.
  - ***Next Step:*** Assessment is complete. Total final score.

SCORE EVALUATION

For I2V application, a corridor score can be evaluated as a combined existing device, safety, congestion, and signals score. Alternatively, corridors may be considered for specific technologies or support if a high score exists in one only category. A higher safety score indicates segments with high crash rates and planned safety improvement that PennDOT could leverage to deploy I2V safety applications such as curve speed warning or red-light violation warning. A higher congestion score indicates where technologies such as queue warnings could be deployed. A higher signals score indicates segments on the corridor with signals already connected to PennDOT's network, facilitating easier communication and transmittal of I2V messages to vehicles. In the future, Transportation Systems Management and Operations (TSMO) will include potential Hard Shoulder Running Locations (HSR) that could be used to identify corridors where HSR information could be transmitted to vehicles.

USE CASE #5: VEHICLE TO INFRASTRUCTURE TRANSIT

SCORING DESCRIPTION & OVERVIEW

Transit vehicles are the strongest example of connected vehicles in sustainable deployment. Transit signal priority systems are functional V2I systems that have been successfully deployed across the country. PennDOT can support local agencies interested in advancing connected transit through facilitating inter-agency coordination between local traffic signal operators and local transit agencies, providing guidance on system planning and operations, and supporting grant applications for funding.

To help target PennDOT support, the V2I scoring rubric is split into two components – corridors with existing TSP and corridors with no existing TSP. Agencies which have not yet deployed TSP are unlikely to be early adopters of other V2I systems, such as pedestrian or object detection, variable speeds for platooning and energy savings, real-time arrivals, and mobility-on-demand. Therefore, the rubric evaluates the use case in a **corridor context** through Step 3 (TSP not yet deployed) OR Step 4 (TSP already deployed) While this is a corridor-based assessment, some questions ask about the capabilities on an agency-wide basis.

METHODOLOGY

- **Step 1:** Define corridor for consideration in the assessment. It should be a contiguous stretch of infrastructure (e.g., pavement, track, etc.) and include the full extent of potential project limits. The ideal corridor is likely the service boundaries of a transit agency. The corridor may include multiple roads.
- **Step 2:** Does the maintaining agency currently use Transit Signal Priority for any route?
    - ***Scoring Type****:* Self-Scoring
    - ***Potential Data Sources:*** Local knowledge
    - ***Rubric Description:*** Select a score, yes or no, based on the self-assessment of the use of TSP for any transit route maintained by the agency. The rubric is a binary score if the corridor does/does not have TSP.
    - ***Rationale:*** While TSP has been available for many years, it is not widely deployed. If an agency has not yet deployed TSP, it is unlikely to be an early adopter of future V2I technology but should still be evaluated for assistance in deploying TSP. If an agency has deployed TSP, it should be evaluated for early deployment of advanced technologies.
    - ***Next Step:*** If no, complete Step 3 only. If yes, complete Step 4.
- **Step 3:** Evaluate Transit Agency Characteristics
    - **Step 3A:** What is the institutional capacity of the transit agency in the corridor?
        - ***Scoring Type*****:** Self-Scoring
        - ***Potential Data Source:*** Local knowledge
        - ***Rubric Description:*** Select a score, 1 to 5, based on the self-assessment of the institutional capacity of the transit agency in the corridor, including their experience coordinating with other agencies.
        - ***Rationale:*** Because PennDOT's role in a transit focused deployment is likely to predict early adopters of technologies and support, rather than lead, institutional capacity that is necessary within the transit agency to ensure deployment and long-term operational success. If score is 3 or above, the corridor may

be a potential candidate to deploy TSP and has demonstrated success in working with other agencies. If score is 2 or below, the corridor likely does not have the capabilities to deploy TSP currently.

- ***Next Step:*** Proceed to Step 3B.

- **Step 3B:** What is the inter-agency coordination between the transit agency and signal owner?
  - ***Scoring Type*****:** Self-Scoring
  - ***Potential Data Source:*** Local knowledge
  - ***Rubric Description:*** Select a score, 1 to 5, based on the self-assessment of the inter-agency coordination between the transit agency and signal owner in the corridor.
  - ***Rationale:*** Because signals are typically not owned by the transit agency, cooperation with the local owning agency is critical. If score is 3 or above, the corridor may be a potential candidate to deploy TSP. If score is 2 or below, the corridor likely does not the coordination needed to deploy TSP currently.
  - ***Next Step:*** Assessment Complete. Total final score.
- **Step 3C:** Does the agency have a communications backbone?
  - ***Scoring Type***: Self-Scoring
  - ***Potential Data Sources***: Local Knowledge
  - ***Rubric Description***: Select a score, 1 to 5, based on the self-scoring assessment of the percent of signals connected to a central system (Transportation Management Center (TMC) or PennDOT network).
  - ***Rationale***: A higher score indicates an advancement of the signal system technology resulting in the likelihood that upgrades to TSP will require less investment.
  - ***Next Step***: Assessment is complete. Total final score.

- **Step 4:** Evaluate Existing Technologies
  - **Step 4A:** Does the agency have real-time transit information systems?
    - ***Scoring Type*****:** Self-Scoring
    - ***Potential Data Source:*** Local knowledge
    - ***Rubric Description:*** Select a score, 1 to 5, based on the self-scoring estimation of the percent of the transit fleet that is equipped with real-time information capabilities (e.g., real time location reporting).
    - ***Rationale:*** A higher score shows adoption of current technology by the agency. This indicates a likelihood to be an early adopter of future technologies.
    - ***Next Step:*** Proceed to Step 4B.
  - **Step 4B:** Does the agency have the ability for real-time passenger counts?
    - ***Scoring Type*****:** Self-Scoring
    - ***Potential Data Source:*** Local knowledge
    - ***Rubric Description:*** Select a score, 1 to 5, based on the self-scoring estimation of the percent of the fleet that can gather real-time passenger counts on vehicles.
    - ***Rationale:*** A higher score indicates potential as a first mover for future V2I technologies (e.g., selective TSP for transit vehicles nearing full capacity of passengers).
    - ***Next Step:*** Proceed to Step 4C.

- **Step 4C:** What is the inter-agency coordination between the transit agency and infrastructure owner?
  - ***Scoring Type***: Self-Scoring
  - ***Potential Data Source:*** Local knowledge
  - ***Rubric Description:*** Select a score, 1 to 5, based on the self-scoring assessment of inter-agency coordination between the transit agency and the infrastructure owner in the corridor or other transit agencies. For rail-based corridors, evaluate coordination with the intersecting signal owner agency(ies).
  - ***Rationale:*** A higher score indicates potential as a first mover for future V2I transit technologies.
  - ***Next Step:*** Proceed to Step 4D.
- **Step 4D:** Does the agency have digital real-time transit information at stations?
  - ***Scoring Type***: Self-Scoring
  - ***Potential Data Source:*** Local knowledge
  - ***Rubric Description:*** Select a score, 1 to 5, based on the self-scoring estimation of the percent of stations/stops with digital real-time information.
  - ***Rationale:*** A higher score indicates potential as a first mover for future V2I transit technologies.
  - ***Next Step:*** Assessment is complete. Total final score.

SCORE EVALUATION

If TSP does not exist (Step 2 Answer = No), this may be an indicator where PennDOT could assist in improving coordination or institutional capacity, or if these capabilities exist, supporting funding for TSP. If TSP already exists (Step 2 Answer = Yes), these agencies may be likely first movers for more advanced V2I technologies in the future for PennDOT investment. High scoring TSP agencies have the institutional and real-time data capabilities to feed advanced innovative V2I applications. Showing agency capability in Steps 4A – 4D is a more important indicator of a corridor's likelihood of early adoption than the current capabilities of the specific corridor being evaluated. For example, a currently low-technology equipped corridor in an otherwise high-capability agency has a higher likelihood of early adoption than a low-technology equipped corridor in a low- or moderate-capability agency.

APPENDIX D: ASSESSMENT TIPS & TRICKS

This appendix outlines some tips and tricks specific to assessing the use cases ADAS and Automated Trucking.

ADAS

- **Step 2**: The most consistent dataset is the RMS-Segments-External layer in One Map (One Map > Layers > Roadway > General Segment Info > RMS Segments External). It has a field for segment direction (one-way north, one-way south, one-way east, one-way west, and bidirectional). It excludes all local roads. The directional length can be calculated as the sum of all single-direction segment lengths, plus twice the bidirectional segment lengths (see Eq. 1 below):

  Eq.1:

  $$\boldsymbol{L_{Total}} = L_{North} + L_{South} + L_{East} + L_{West} + 2(L_{Bidirectional})$$

- **Step 3B**: To obtain length of asphalt segments resurfaced in the last 10 years, filter layer by field Layer Type = “Bituminous wearing”, field SEQ_NO = “1”, and field Layer_Year ≥ [your current year minus 10]. This returns the most recent (i.e., first) bituminous wearing course that was put down within the last 10 years. Sum up the lengths.

  For the concrete, filter layer by field Layer Type = “Concrete wearing”, field SEQ_NO = “1”, and field Layer_Year ≥ [your current year minus 25]. This returns the most recent (i.e., first) bituminous wearing course that was put down within the last 25 years. Sum up the lengths.

  The process should be repeated for Layer Type = “Bridge deck” and added to the concrete figure, as most bridge decks are concrete.

- **Step 4A**: Make sure to use the <u>OR</u> operator to select individual crash types (e.g., “Rear End” <u>OR</u> “Backup (Congestion) <u>OR</u> Backup (Non-recurring incident/event <u>OR</u> Backup (Prior Crash)”). The default operator is AND, which will select crashes where all selected crash types are present, which drastically reduces the number of crashes.

AUTOMATED TRUCKING

- **Step 3A**: The *weighted average AADTT across the corridor, weighted by distance* can be computed using the layer “RMS Traffic – All”. Export the file to Excel. The layer has a field “ADTT_CUR” that contains current truck traffic counts by segment. Compute the weighted average by summing the products of each segment ADTT by its length, and dividing that sum by the total of all segment lengths, as shown in the formula below:

  =SUMPRODUCT([ADTT_CUR]*[SEG_LENGTH_FT]/SUM([SEG_LENGTH_FT]))

- **Step 3B**: This step requires a slight workaround. The layer used to obtain the length in Step 2 (“RMS – Admin – External”) allows us to calculate directional length but does not have a field for functional classification. By contrast, the layer “RMS - ADMIN - All" does have a functional class field, but not a direction field with which to determine directional length. As a workaround, use the "RMS - ADMIN - All" layer filtered to all non-local roads ("FHWA_FUNC_CLS" > 7), which will at least select the same segments as Step 2. From there, use the functional classification field to select out each type of classification and divide it by the total length of non-local roads to obtain an approximate percentage. This will slightly understate the proportion of divided highways and other one-way segments.

- **Step 4:** Filter the layer by RANKING_BY_ABR > [each threshold from the rubric].