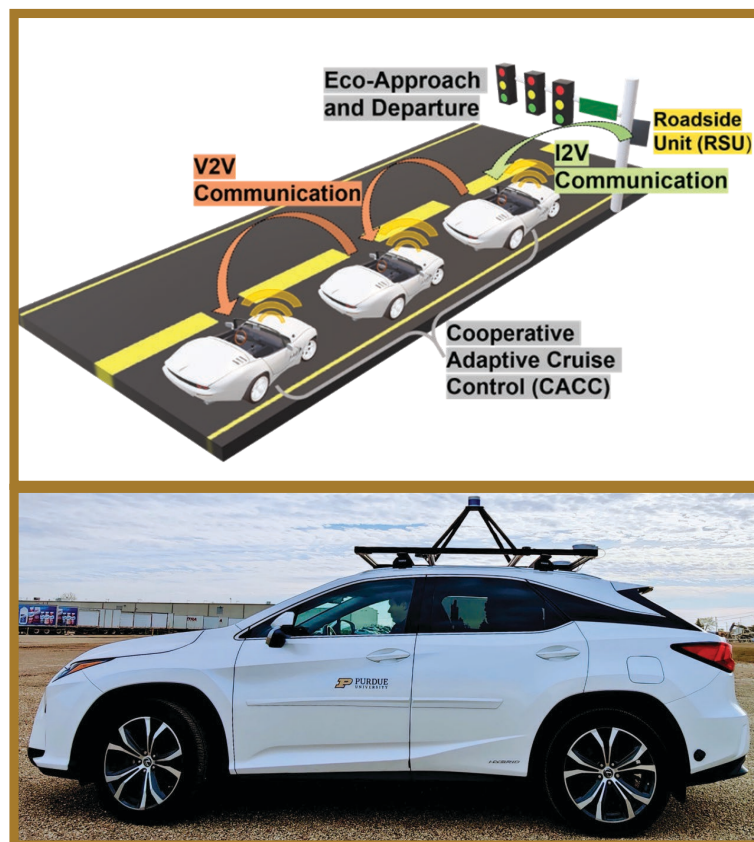


# JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION  
AND PURDUE UNIVERSITY



## Feasibility Study on the Development of Indiana's Connected and Automated Vehicle Roadmap and Strategic Plan



**Can Cui, Juanwu Lu, Yupeng Zhou, Abin Mathew,  
Jue Zhou, Ziran Wang, and Yaobin Chen**

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## JOINT TRANSPORTATION RESEARCH PROGRAM

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## EXECUTIVE SUMMARY

### Introduction

The rapid advancement of connected and automated vehicle (CAV) technologies offers unprecedented opportunities while also posing significant implementation challenges for state transportation agencies. Indiana, positioned at the literal and figurative crossroads of America, must navigate this technological transformation while maintaining its commitment to safety, efficiency, and economic vitality. CAVs will share infrastructure with conventional vehicles for many years, which requires the Indiana Department of Transportation to plan investments that deliver measurable safety and mobility benefits under mixed traffic conditions. At the same time, original equipment manufacturers (OEMs) are sequencing feature roadmaps according to regulatory clarity, market demand, and infrastructure readiness. This feasibility study is designed to resolve that problem by translating national and regional experience, stakeholder input, and technology evaluations into an implementable strategic direction for Indiana.

This study evaluates the state of practices within the Mid-America Association of State Transportation Officials (MAASTO) region and beyond to extract deployment patterns that are relevant to Indiana's network. Emphasis is placed on corridor-scale programs, urban safety pilots, and rural demonstrations that reveal how sensing and Vehicle-to-Everything (V2X) communications perform under real operating constraints. A core element of the project is structured engagement with major OEMs and key stakeholders. Direct interviews with automotive CAV experts from OEMs capture industry perspectives on infrastructure requirements, short- and long-term product

strategies, and business model viability. From a technical perspective, the evaluation focuses on sensing and communications elements that underpin safety and mobility applications. Cellular Vehicle-to-Everything (C-V2X) pathways are evaluated to clarify latency, reliability, and coverage tradeoffs in Indiana's deployment context. This project also includes an assessment of the resources required inside INDOT's operations, information technology, and traffic management units. Lessons learned from peer agencies are synthesized into staffing profiles, role definitions, and process controls that lower operational risk during deployment and sustainment.

### Findings

The report delivers three outputs that guide the CAV technologies implementation in Indiana.

- It synthesizes the best regional practices and industry direction to distinguish what is feasible now from what requires further development.
- It establishes a technical baseline that links priority applications to sensing and communications architectures with explicit attention to interoperability, security, and maintainability.
- It defines an implementation framework that connects capital and operating investments to organizational capabilities, funding sources, and measurable outcomes for safety and mobility.

### Implementation

Future work should convert these findings into a detailed CAV strategic plan for Indiana that balances safety, efficiency, and innovation. The next steps are to outline a phased implementation roadmap with immediate, near-term, and long-term actions and milestones.

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## 1. INTRODUCTION

The rapid advancement of connected and automated vehicle (CAV) technologies presents both unprecedented opportunities and complex implementation challenges for state transportation agencies. As vehicles increasingly incorporate sophisticated sensing, communication, and automation capabilities, the traditional boundaries between infrastructure, vehicles, and digital systems continue to dissolve. Indiana, positioned at the literal and figurative crossroads of America, must navigate this technological transformation while maintaining its commitment to safety, efficiency, and economic vitality. CAVs will share infrastructure with conventional vehicles for many years, which requires the Indiana Department of Transportation (INDOT) to plan investments that deliver measurable safety and mobility benefits under mixed traffic conditions. At the same time, original equipment manufacturers (OEMs) are sequencing feature roadmaps according to regulatory clarity, market demand, and infrastructure readiness. These dynamics create a planning problem that is technical, institutional, and economic. This feasibility study is designed to resolve that problem by translating national and regional experience, stakeholder input, and technology evaluations into an implementable strategic direction for Indiana.

This study evaluates the state of practices within the Mid-America Association of State Transportation Officials (MAASTO) region and beyond to extract deployment patterns that are relevant to Indiana's network. Emphasis is placed on corridor-scale programs, urban safety pilots, and rural demonstrations that reveal how sensing and Vehicle-to-Everything (V2X) communications perform under real operating constraints. The analysis distinguishes between technologies that are mature enough for scaled adoption and those that remain suitable for research pilots. It also identifies organizational prerequisites, including asset governance, cybersecurity boundaries between operations and enterprise information technology (IT), and the workforce skills needed to operate and maintain CAV infrastructure. A core element of the project is structured engagement with major OEMs and key stakeholders. Direct interviews with automotive CAV experts from OEMs capture industry perspectives on infrastructure requirements, short- and long-term product strategies, and business model viability.

From a technical perspective, the evaluation focuses on sensing and communications elements that underpin safety and mobility applications. Roadside Units (RSUs) are assessed as integrated perception and communications platforms that host cameras, Light Detection and Ranging (LiDAR), radar, and associated edge processing. Comparative analysis of these modalities is used to recommend sensor packages for specific operational design domains and environmental conditions. Cellular Vehicle-to-Everything (C-V2X) pathways are evaluated for both direct short-range links and network-based links to clarify latency, reliability, and coverage of trade-offs in Indiana's deployment context. The study also examines the concept of virtual Roadside Units that replicate physical RSU functions using edge and cloud resources where physical installations are impractical or cost prohibitive.

Because technology without organizational readiness does not scale, the project includes an assessment of the resources required inside INDOT's operations, information technology, and traffic management units. This assessment considers device lifecycle management, firmware and configuration control, integration with signal systems, data governance and privacy, cybersecurity segmentation, and vendor support models. Lessons learned from peer agencies are synthesized into staffing profiles, role definitions, and process controls that lower operational risk during deployment and sustainment.

The remainder of this report is organized as follows:

- Chapter 2 presents research and analysis of regional CAV roadmap initiatives in the MAASTO region, with attention to program scope, delivery models, and performance evidence.
- Chapter 3 reports the results of stakeholder surveys and OEM partnership analysis, including near- and long-term deployment priorities and the implications for public-private collaboration.
- Chapter 4 provides a technological and infrastructure evaluation that covers RSUs, common sensors, virtual RSUs, and traffic optimization concepts for signalized corridors.
- Chapter 5 presents an organizational resource assessment that defines roles, staffing, asset management practices, and data governance needed to operate CAV infrastructure reliably.
- Chapter 6 concludes the report and outlines future work that includes continued industry engagement, evaluation plans for pilots, and updates to standards and specifications as technologies and regulations evolve.

## 2. RESEARCH AND ANALYSIS OF REGIONAL CAV ROADMAP INITIATIVES

The deployment of CAV technologies across the United States has been driven by a combination of state-level innovation, federal support, and private-sector investment. Within the MAASTO region, several states have established roadmaps, pilot programs, and strategic initiatives that provide important insights into best practices, challenges, and future opportunities. This chapter conducts a comparative analysis of these regional initiatives, with the objective of identifying lessons learned that can inform Indiana's CAV roadmap and strategic plan.

The analysis covers four states: Michigan, Ohio, Minnesota, and Wisconsin. Each of them has pursued distinct approaches to advancing CAV technologies. Michigan and Ohio have committed substantial resources to large-scale infrastructure deployments and freight automation corridors. Minnesota prioritizes accessibility and rural mobility through targeted pilot programs. Wisconsin, meanwhile, has concentrated on building financial and policy frameworks to capitalize on emerging federal opportunities. This strategic diversity offers Indiana multiple models to consider as it charts its own course. For each state, the review examines how its roadmap addresses safety, innovation, collaboration, legislation, and long-term transportation needs. The evaluation further considers the degree of alignment with key policy objectives, including safety enhancements, efficiency improvements, technology integration, and transportation system resilience.

By examining these varied strategies against Indiana’s specific context, we identify both transferable practices and unique opportunities for the state to establish CAV leadership in the Midwest.

## 2.1 State of Michigan

As the historical center of American automotive manufacturing, Michigan has naturally evolved itself as a national leader in CAV deployment through large-scale pilot programs, corridor development, and strong public–private partnerships. Its CAV roadmap emphasizes innovation, roadway safety, and the integration of advanced vehicle technologies into real-world transportation networks.

### 2.1.1 Safety Pilot Model Deployment: An Early Technical and Research Foundation

One of Michigan’s earliest initiatives was the Safety Pilot Model Deployment, led by the University of Michigan Transportation Research Institute (UMTRI). This project installed dedicated short-range communication (DSRC) devices on 3,000 vehicles, including passenger cars, trucks, and transit vehicles, to test safety-critical applications under real-world conditions. Operating on public streets in Ann Arbor, the deployment created a concentrated test environment with roadside equipment, data acquisition systems, and weather monitoring. The program generated valuable insights into vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, establishing the technical and operational foundations for subsequent CAV projects.

### 2.1.2 Cavnue CAV Corridor

Michigan’s most ambitious current initiative is the Cavnue CAV Corridor (Cavnue, n.d.), developed in partnership between the Michigan Department of Transportation (MDOT), State of Michigan Government, City of Detroit, Michigan Department of Labor and Economic Opportunity, and a coalition of public and private partners including Michigan Economic Development Corporation, Ford, the University of Michigan, and the American Center for Mobility. As shown in Figure 2.1, they are developing the first dedicated CAV corridor along Interstate 94 (I-94), connecting Detroit and Ann Arbor over a 40-mile stretch. The initial phase converts the left lane into a technology-enabled express lane equipped with radar, sensors, and wireless communication systems. Flexible posts separate traffic to enable controlled CAV testing during off-peak hours. No personal data is being collected during testing; all data collected is for the evaluation of safety and mobility technologies.

The corridor project focuses on improving safety, reducing congestion, and enhancing freight and passenger mobility. It also aims to encourage integration of smart road technologies such as advanced pavement monitoring, improved incident response, and enhanced transit access. Importantly, the initiative explores new funding mechanisms, including the potential

introduction of optional user fees for CAV operators, which could sustain long-term operations and address declining fuel tax revenues driven by increased efficiency and electric vehicle adoption.

- **Purpose, Need, and Strategic Rationale:** The CAV corridor was conceived to bridge the gap between in-vehicle automation technologies and roadway infrastructure. Its stated purposes include upgrading roadways with smart technology, improving safety and roadway operations, supporting reliable transit routes, and encouraging sustainable transportation modes. Identified needs focus on reducing crashes, improving maintenance and incident response capabilities, and ensuring equitable access to future mobility services.
- **Potential for User Fees:** A user fee is a fee that drivers may choose to pay to experience the full benefits of a lane. In the future, when CAVs are more widely adopted, there may be an optional user fee for CAV drivers who want to experience all the benefits of the CAV corridor, ensuring that the project is funded directly by those who benefit from it. The fee would be a choice made by CAV drivers using the lane, and it would not be required of all vehicles. This fee would fund the ongoing operation and maintenance of the lane and help bridge the projected gas tax funding shortfalls driven by improved fuel economy and the proliferation of electric vehicles. The ability to charge a user fee is subject to both state and federal approvals.
- **Financial and Policy Considerations:** The financial structure of the corridor is evolving, with initial feasibility and design studies privately funded by Cavnue. MDOT has provided staff resources and coordination, but direct funding commitments are limited. Recent reports indicate that Cavnue raised \$130 million to support corridor development, with construction expected to be predominantly privately financed. This model illustrates Michigan’s policy emphasis on leveraging public–private partnerships to advance large-scale mobility innovations without overburdening public budgets.

### 2.1.3 Timeline

Michigan’s initiatives illustrate the value of large-scale pilots and corridor projects as living laboratories for CAV integration. The focus on collaboration between state agencies, universities, and private-sector partners demonstrates an effective model for advancing innovation while distributing costs and risks. Additionally, the exploration of user fees offers a proactive approach to long-term funding sustainability, which may serve as a useful reference for Indiana in developing its own CAV investment strategies. The time is showing in Figure 2.2.

## 2.2 State of Ohio

Ohio has transformed its geographic centrality and logistics importance into strategic advantages for CAV development. The state’s efforts are coordinated through DriveOhio (DriveOhio, n.d.), a smart mobility initiative within the Ohio Department of Transportation (ODOT), which facilitates collaboration across public agencies, research institutions, and private industry (Figure 2.3).

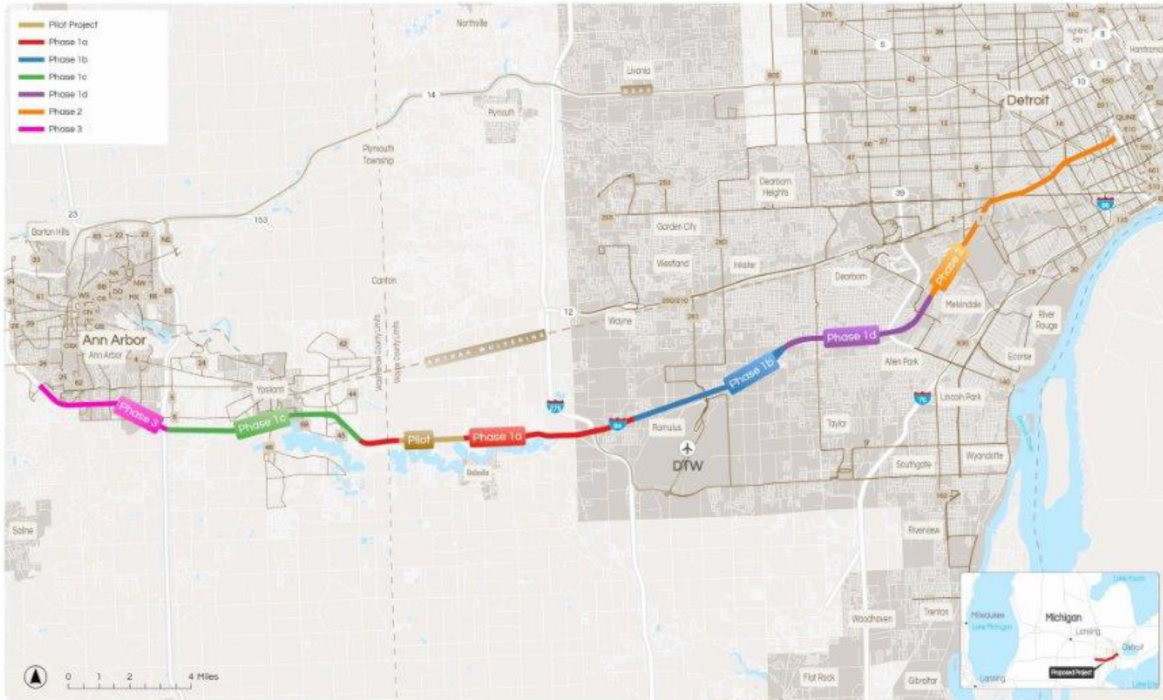


Figure 2.1 The I-94 CAV Corridor Projects Map (Michigan Department of Transportation, n.d.).

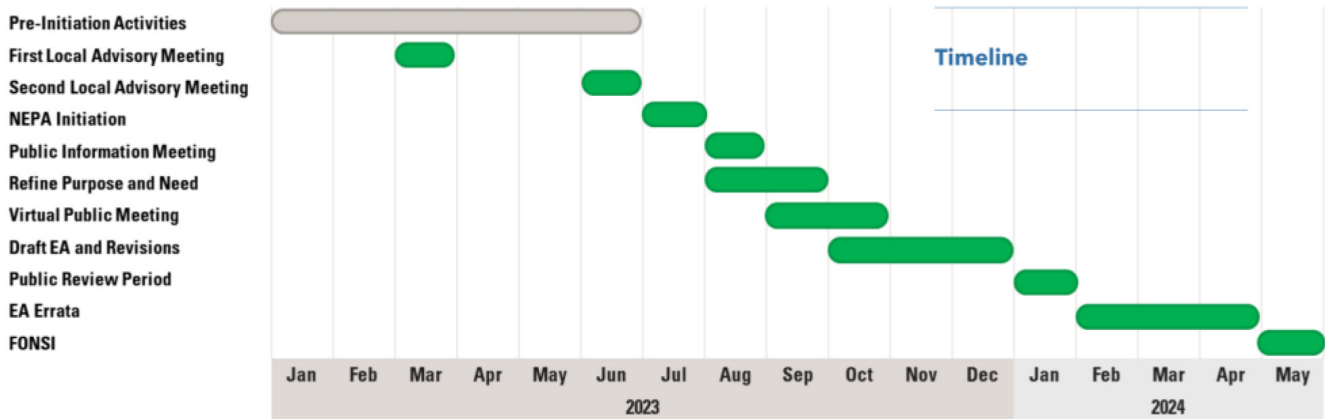


Figure 2.2 CAV Corridor Projects Timeline (Cavnue, n.d.).



Figure 2.3 DriveOhio CAV Projects Map (DriveOhio, n.d.; AASHTO Journal, 2023).

### 2.2.1 33 Smart Mobility Corridor

The 33 Smart Mobility Corridor is a 35-mile stretch of U.S. Route 33 northwest of Columbus, designed as a real-world proving ground for automated and connected vehicles. The corridor is equipped with a 432-strand fiber optic network, roadside sensors, and communication units installed in vehicles and infrastructure, enabling instantaneous data sharing between vehicles, researchers, and traffic monitors. The project involves more than 70 automotive and technology companies and has been supported by \$100 million in public and private investment, including \$15 million in fiber installation by ODOT, \$5.9 million in U.S. Department of Transportation (USDOT) Smart Infrastructure Grants, and \$45 million in funding for the Transportation Research Center’s (TRC) SMARTCenter.

Pilot projects along the corridor have included deployment of small autonomous shuttles operating in mixed-use areas such as residential neighborhoods, hospitals, and commercial districts. This initiative demonstrates Ohio’s ability to integrate large-scale infrastructure investment with applied CAV research.

### 2.2.2 I-70 Truck Automation Corridor

The Interstate 70 (I-70) Truck Automation Corridor represents Ohio’s commitment to advancing automation in freight and logistics. Spanning 166 miles between Columbus, Ohio, and Indianapolis, Indiana, the corridor is a binational collaboration between ODOT, INDOT, DriveOhio, and the TRC. The \$8.8 million project (2021–2027) deploys varying levels of truck automation, including platooning, with a professional driver always at the wheel for safety oversight.

The corridor aims to integrate automation technologies into daily freight-hauling operations, supporting efficiency gains, safety improvements, and industry adoption of CAV freight practices. The project timeline, as indicated in Figure 2.4, includes phased deployments, with initial road audits (2022–2023), procurement for higher automation levels (2024), platooning deployments (2024–2025), and full project evaluation by 2027. This project highlights Ohio’s role in freight innovation and cross-border collaboration with Indiana.

### 2.2.3 Rural Automated Driving Systems

Recognizing that CAV deployment must extend beyond urban and highway environments, Ohio has also invested in rural automation research. Through a \$7.5 million USDOT Automated Driving Systems (ADS) Demonstration Grant, the DriveOhio-led consortium (TRC, JobsOhio, AutonomouStuff, University of Cincinnati, Ohio University, and Bosch) is testing automated vehicle operations on rural roadways in central and southeast Ohio. The focus is on collecting performance data for automated systems navigating curves, hills, shaded areas, and other rural roadway challenges. This initiative addresses an often-overlooked element of CAV deployment: ensuring equitable and safe technology integration for rural populations and freight routes. The data collected will inform national research on the safety and reliability of automated systems under diverse roadway conditions.

## 2.3 State of Minnesota

Minnesota has adopted a comprehensive and community-centered approach to connected and automated vehicle deployment through its Destination CAV Strategic Plan and a series of pilot

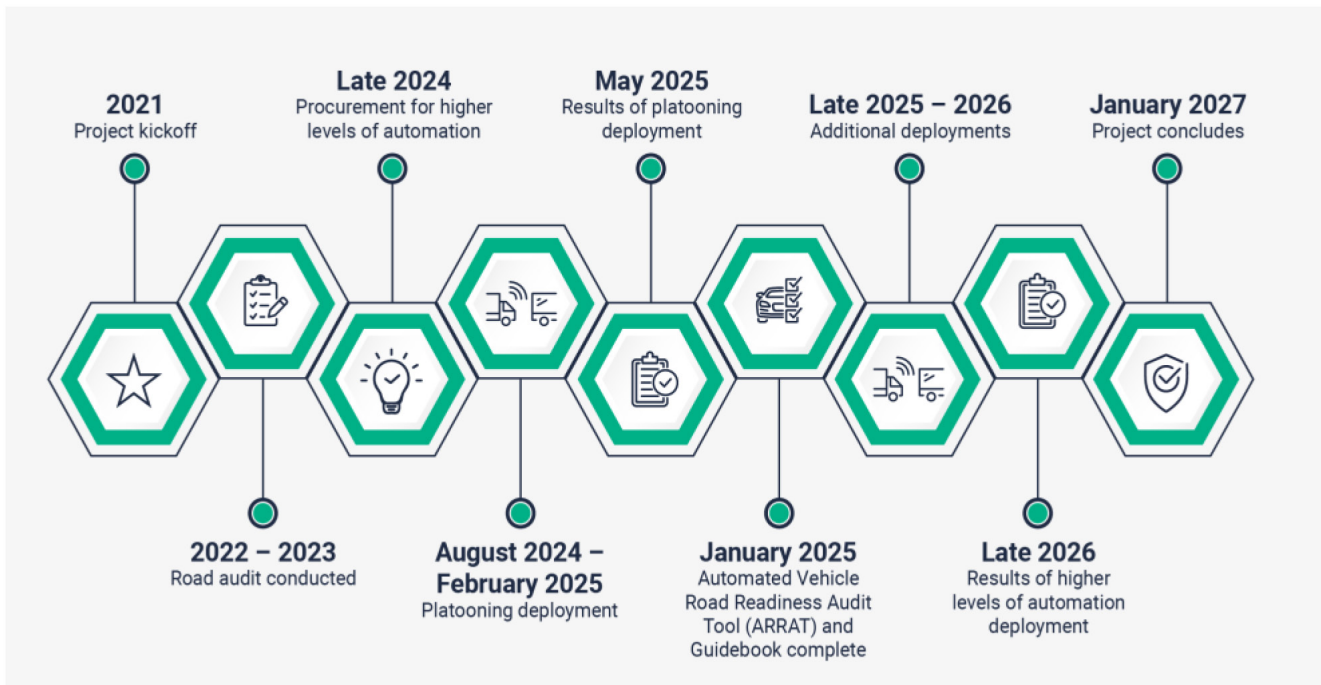


Figure 2.4 I-70 Truck Automation Corridor Timeline (DriveOhio, n.d.).



**Figure 2.5** Med City Mover Project (Minnesota Department of Transportation, n.d.b).

programs emphasizing accessibility, rural mobility, and integration with existing transit networks. The state’s roadmap demonstrates a balance between strategic long-term planning and localized pilot implementations designed to address the diverse needs of urban, suburban, and rural communities.

### 2.3.1 Destination CAV MnDOT’s CAV Strategic Plan

Originally released in 2019, the Destination CAV plan provides statewide direction for advancing CAV technologies. The Minnesota Department of Transportation (MnDOT) collaborated with stakeholders across the state to identify 65 short-, medium-, and long-term strategies to prepare for changes in transportation

(Minnesota Department of Transportation, n.d.c). These strategies span safety, mobility, infrastructure modernization, and public engagement. The plan also established a funding framework, allocating up to \$2.5 million annually to support local stakeholders and potential partners in testing and implementing innovative transportation solutions. This funding mechanism highlights Minnesota’s commitment to collaborative investment in both infrastructure and community-driven projects.

### 2.3.2 Med City Mover

The Med City Mover project (Minnesota Department of Transportation, n.d.b), launched in Rochester, Minnesota, tested two six-passenger automated electric shuttles along a programmed downtown route (Figure 2.5). The project focused on demonstrating how low-speed, self-driving shuttles could enhance first-/last-mile connectivity in mixed-use urban areas. Supported by a \$1.5 million investment, the shuttles operated from 2021 to 2022, providing valuable insights into public acceptance, operational reliability, and integration with existing transit services.

### 2.3.3 Bear Tracks

The Bear Tracks project (Minnesota Department of Transportation, n.d.a), operated in White Bear Lake, focused on expanding automated shuttle services into suburban communities (Figure 2.6). The initiative sought to provide residents with a safe and accessible transportation option, particularly targeting individuals with mobility or transportation challenges. Launched in April 2022, the project operated until August 2023 with \$900,000 in state investment and included partnerships with international vehicle manufacturers. This project demonstrated the feasibility of suburban deployment and highlighted opportunities for mobility equity in smaller communities.

### 2.3.4 goMARTI

The goMARTI project (goMARTI, n.d.) in Grand Rapids, Minnesota, represents one of the nation’s first large-scale rural (autonomous vehicle) AV shuttle deployments (Figure 2.7).



**Figure 2.6** Bear Tracks Project (Minnesota Department of Transportation, n.d.a).



Figure 2.7 goMARTI Self-Driving Shuttle Project (goMARTI, n.d.).

Operating in partnership with multiple public and private organizations, the project tests the use of automated vehicles in challenging rural and winter conditions. With more than \$13 million in funding (including a \$9.3 million expansion grant in 2023), goMARTI advances research on how automation can improve mobility for residents with limited transportation access. The project emphasizes inclusivity, aiming to serve individuals with disabilities and other transportation disadvantages.

## 2.4 State of Wisconsin

Wisconsin’s CAV roadmap is structured primarily around funding readiness and strategic positioning to support future deployment. While other states have emphasized pilot deployments and test corridors, Wisconsin Department of Transportation (WisDOT)

has focused on building a strong financial and policy foundation that can enable rapid adoption of connected and automated vehicle projects when opportunities arise (WisDOT, 2024, n.d.a).

### 2.4.1 Bipartisan Infrastructure Law Funding

WisDOT’s CAV initiatives are supported by multiple funding streams: the Bipartisan Infrastructure Law (BIL), USDOT CAV-specific allocations, federal discretionary grants, and state-level programs. Collectively, these mechanisms ensure that Wisconsin can competitively pursue federal opportunities while providing matching funds or supplemental state resources. WisDOT also manages specialized safety-oriented funding, such as the Law Enforcement Traffic Safety Grants (BOTS; WisDOT, n.d.d) and the Highway Safety Improvement Program (HSIP; WisDOT, n.d.c), which can be leveraged to integrate CAV technologies into roadway safety strategies.

Under the BIL, Wisconsin has been awarded \$2.22 billion in infrastructure funding, distributed across state program grants and discretionary grant competitions (Figure 2.8). While no projects are currently designated exclusively as “CAV-related,” the state has emphasized readiness to apply these funds toward CAV projects as federal priorities evolve.

### 2.4.2 Federal Discretionary Programs

WisDOT maintains a Summary Guide to Federal Discretionary Grants, highlighting current funding opportunities and ensuring eligibility for competitive programs (WisDOT, n.d.b; Table 2.1).

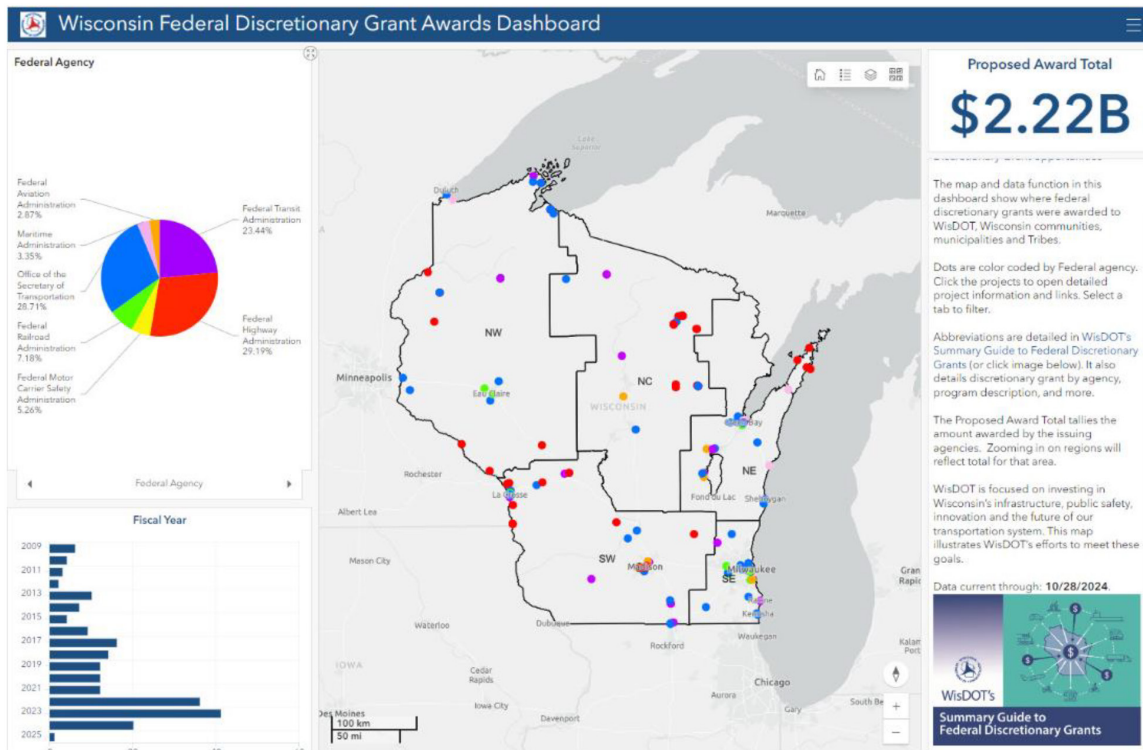


Figure 2.8 BIL Funding (WisDOT, n.d.c).

TABLE 2.1  
Current Notice of Funding Opportunities.

Program	Agency	Funding Amount
Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT)	FHWA (Grants.gov, 2025)	\$876,000,000
Tribal Transportation Program Safety Fund (TTPSF)	FHWA (n.d.)	\$24,518,400
Federal State Partnership for Intercity Passenger Rail (FSP National)	FRA (n.d.)	\$1,057,596,637
National Scenic Byways Program	FHWA (2025)	\$26,950,000
Tribal Transit Program (TTP)	Federal Transit Administration (FTA, n.d.)	\$9,169,076

As of October 2024, Wisconsin is monitoring programs such as the Promoting Resilient Operations for Transformative and Cost-Saving Transportation (PROJECT) initiative (\$876 million nationally; Grants.gov, 2025), the Tribal Transportation Program Safety Fund (TTPSF; Federal Highway Administration [FHWA], n.d.), and the Federal-State Partnership for Intercity Passenger Rail (FSP; \$1.06 billion nationally; Federal Railroad Administration [FRA], n.d.). By tracking these opportunities, WisDOT itself can integrate CAV-related infrastructure enhancements into larger federally funded transportation projects.

### 3. OEMs PATERNERSHIP ANALYSIS AND SURVEY

Understanding the automotive industry’s perspective on connected and automated vehicle deployment is essential for developing an effective state roadmap. OEMs control the pace of in-vehicle technology adoption, define technical requirements for infrastructure interfaces, and ultimately determine which applications reach consumers. However, the industry continues to face barriers related to regulatory uncertainty, infrastructure investment, and the enduring “chicken-and-egg” dilemma of whether vehicles or infrastructure should lead to adoption. To address these issues, this study conducted structured interviews with experts from leading OEMs to capture their perspectives on CAV deployment challenges, technological opportunities, and potential pathways for collaboration with state departments of transportation. The following subsections summarize the perspectives of two representatives, highlighting their views on infrastructure, the deployment of connected and automated vehicles, and the opportunities for Indiana to align with national and industry trajectories.

#### 3.1 Interview Insights of an Automotive Expert from OEM A

As part of the stakeholder engagement process, project Principal Investigators (PIs) conducted an interview with a senior technical expert from OEM A. The discussion reflected his personal perspectives on the state of connected vehicle deployment, regulatory challenges, and the role of infrastructure

in enabling CAV integration. While not an official corporate statement, the interview provides valuable insights into OEM A’s thinking and the broader industry landscape.

##### 3.1.1 Infrastructure and Investment Needs

This expert’s infrastructure assessment challenges conventional assumptions about deployment requirements while identifying pragmatic pathways for near-term progress. Rather than advocating for a comprehensive, immediate infrastructure overhaul, the expert outlined a surgical approach that maximizes impact while managing costs, a perspective that aligns well with INDOT’s resource constraints and existing asset base. This expert emphasized that large-scale deployment does not need to occur at all at once. Instead, incremental investment in critical intersections should be prioritized, particularly those with high crash rates and frequent conflicts, with vulnerable road users such as pedestrians and cyclists. INDOT’s existing highway provides a strong foundation for equipping intersections with RSUs.

**3.1.1.1 Incremental Infrastructure Investments.** Recent developments, including the Federal Communications Commission’s (FCC) finalization of spectrum rules and the forthcoming USDOT’s national V2X deployment plan, suggest a potential inflection point for progress. Federal funding through the Infrastructure Investment and Jobs Act (IIJA) has also shifted strategies from “vehicle-first” to “infrastructure-first,” with state departments of transportation (DOTs) and municipalities taking a leading role.

**3.1.1.2 Infrastructure-First Deployment Strategy.** The conversation highlighted a fundamental strategic shift from a vehicle-first to an infrastructure-first approach. As this expert explained, infrastructure owner-operators (IOOs) are responsible for deploying roadside sensors and communication modules, while automakers will respond once coverage expands (“if they build it, we will come”). For Indiana, this means targeting high-impact corridors such as I-80/94 and major metropolitan corridors as pilot implementation sites. Indianapolis also has the potential to position itself as a smart city testbed, replicating successful models such as Columbus, Ohio.

**3.1.1.3 Lessons from Other States.** This expert’s company closely follows lessons from states like Utah, Michigan, Texas, and Georgia, which aggressively pursued V2X deployment through FCC waivers. These early projects demonstrated how corridor-based and city-based pilots can accelerate adoption. This expert also noted Honda’s corridor initiative in Ohio as a model for how public-private partnerships can advance deployment.

##### 3.1.2 Regulatory and Business Context

The regulatory and business environment surrounding V2X deployment has experienced dramatic shifts that fundamentally alter stakeholder calculations. Understanding these dynamics

is essential for positioning Indiana’s investments to align with industry trajectories and federal priorities.

**3.1.2.1 Regulatory Uncertainty.** V2X progress has long been hindered by uncertainty over the 5.9 GHz spectrum rules. It was noted that some OEMs, paused their 2018 DSRC deployment plans due to the FCC’s anticipated spectrum changes and lack of alignment from other OEMs. Recent FCC actions and USDOT’s National V2X Deployment Plan have provided renewed clarity, opening the door for coordinated industry action.

**3.1.2.2 The Chicken-and-Egg Problem.** This expert described the deployment challenge as a chicken-and-egg dilemma: automakers hesitate without widespread infrastructure, while agencies are cautious without automaker commitments. Federal investment through the IIJA is helping break this cycle by funding infrastructure-first deployment.

**3.1.2.3 Business Model Viability.** OEMs require clearer evidence of improvements in customer benefit safety, traffic efficiency, and environmental gains—to justify large-scale V2X investments. Demonstrating return on investment (ROI) for both states and automakers is essential for market sustainability.

### 3.1.3 Technological Considerations

The technical architecture for V2X deployment has matured significantly, with standardized protocols and proven hardware ready for deployment. However, the expert emphasized critical nuances in how these technologies should be integrated with vehicle automation systems and existing infrastructure.

**3.1.3.1 V2X as a Complementary Technology.** This expert argued that automated vehicles must be capable of safe operation independently of connectivity, but V2X can enhance performance through:

- Cooperative perception: sharing sensor data for blind spots and hidden hazards.
- Cooperative maneuvering: coordinating merges and intersection movements.
- Cooperative localization and mapping: improving positioning accuracy and situational awareness.

**3.1.3.2 Infrastructure Capabilities.** Mature standards, such as SAE J4501 for roadside units, ensure interoperability across deployments. Elevated sensors like LiDAR and high-resolution cameras can expand detection beyond vehicle capabilities, supporting comprehensive situational awareness.

### 3.1.4 Strategic Vision for Automated Vehicles

The expert’s perspective on automation deployment domains reveals a pragmatic progression from controlled environments to complex urban settings, with each stage building technical capabilities and public acceptance for subsequent phases.

**3.1.4.1 Incremental Deployment Domains.** This expert identified three domains where automation will likely advance first:

- Highway corridors, with fewer variables for high-speed automated driving.
- Controlled parking zones, where autonomous valet systems can deliver immediate customer value.
- Urban areas, with pilot programs addressing complex mobility challenges.

**3.1.4.2 Challenges of Full Automation.** While optimism exists around commercial robo-taxi services, such as Waymo, achieving Level 5 automation remains difficult. Automated driving systems must be designed to operate safely without connectivity but can achieve greater efficiency and reliability when integrated with V2X.

### 3.1.5 Opportunities for INDOT

To maintain momentum and accelerate deployment, INDOT has identified several strategic opportunities:

- **National Leadership Positioning:** Establish Indiana as a premier testbed for CAV technologies by branding its unique role as the “Crossroads of America” and demonstrating large-scale infrastructure readiness.
- **Incremental Pilot-to-Scale Framework:** Initiate pilots at high-priority intersections and corridors, collect performance and safety data, and expand deployments based on measurable outcomes.
- **Public–Private Partnerships:** Leverage partnerships with universities (e.g., Purdue University), industry stakeholders, and OEMs to share risks, pool expertise, and drive innovation.
- **Federal and State Funding Alignment:** Maximize discretionary opportunities available under the IIJA and other federal programs to accelerate infrastructure-first investments.
- **Stakeholder Communication and Outreach:** Publicize successful pilots to increase public trust, attract additional federal and private-sector funding, and incentivize broader OEM participation.

This expert’s perspective illustrates the opportunities and barriers facing V2X deployment in the U.S. The technical foundation is mature, and Indiana’s infrastructure assets provide a strong starting point. However, regulatory stability, business model clarity, and automaker alignment remain decisive factors. For INDOT, pursuing targeted infrastructure-first strategies and building partnerships can position the state as a leader in connected and automated vehicle integration.

## 3.2 Interview Insights of an Expert from OEM B

An interview was conducted with a senior technical expert from OEM B to understand industry perspectives on CAV development. The discussion reflected his personal insights rather than official corporate positions, but it provides an important view into how major OEMs assess infrastructure requirements, business models, and deployment strategies for V2X technologies.

### 3.2.1 Infrastructure and Investment Needs

With the infrastructure of OEM B's requirements analysis, informed by extensive pilot project experience, this expert challenges some conventional assumptions about sensor deployment while reinforcing others about computational architecture and cost constraints. These insights have direct implications for how INDOT should prioritize infrastructure investments.

**3.2.1.1 Sensor and Computing Requirements.** This expert emphasized that early infrastructure pilots often deployed a wide range of sensors, but experience has shown that LiDAR provides the most effective solution for intersection safety and cooperative driving automation. Cameras and radars remain useful in occluded areas. Infrastructure-based sensing is particularly important for vulnerable road user (VRU) detection, as advanced sensors can help identify pedestrians, cyclists, and unexpected obstacles, providing alerts or emergency braking support to connected vehicles.

**3.2.1.2 Edge Computing for Real-Time Processing.** Because vehicle-side ECUs are resource-constrained, OEMs prefer to offload computationally intensive tasks to infrastructure-based edge devices. These edge systems can aggregate point cloud data, validate messages, and transmit only critical information to vehicles, thereby ensuring low latency and high reliability for safety applications. This expert stressed that message validation is crucial: inaccurate or delayed warnings could compromise safety and increase liability concerns for OEMs.

**3.2.1.3 Cost Considerations.** High costs remain a major barrier to widespread deployment. State DOTs, including INDOT, struggle to justify intersection upgrades exceeding \$1,000 per site. As a result, investment must be prioritized for high-risk corridors and intersections using data-driven methods such as crash history analysis. Not every location requires full sensorization. The hotspot targeting is a practical way to balance costs with safety improvements.

### 3.2.2 High-Impact Applications and Industry Roadmap

This expert addressed that his company's application priorities reflect a pragmatic focus on enhancing existing vehicle capabilities while building toward more ambitious automation goals. This evolutionary approach emphasizes business model viability alongside technical capability.

**3.2.2.1 Near-Term Applications.** OEMs see greater value in V2X deployments that improve existing driver assistance systems (ADAS) and generate measurable business cases. This expert identified several high-impact use cases:

- Electronic tolling through V2X eliminates manual payments and transponders while generating revenue for DOTs and OEMs.
- Queue spillover management, where infrastructure detects and communicates traffic queues to oncoming vehicles, enabling automated speed reductions and congestion prevention.

- Connected ADAS (L2+) enhancements, where local hazard warnings, work zone alerts, and dynamic traffic data can improve longitudinal and lateral control functions.

**3.2.2.2 Long-Term Vision for Cooperative Driving Automation (CDA).** In the longer term, V2X will support urban safety (blind intersections, left-turn conflicts), enhance freeway situational awareness during adverse weather (e.g., snow, fog, heavy rain), and strengthen VRU protection through real-time infrastructure-to-vehicle communication. These applications provide both safety and efficiency benefits, laying the foundation for higher levels of cooperative automation.

**3.2.2.3 Challenges of Adoption.** This expert's perspective mirrors broader industry concerns:

- The **chicken-and-egg problem** persists, as OEMs hesitate to mass-deploy V2X without sufficient infrastructure, while DOTs are reluctant to invest without OEM commitments.
- **Lack of standardization** across states creates fragmented deployments and slows nationwide adoption.

### 3.2.3 Role of Infrastructure Owners and Operators

The expert articulated clear expectations for how transportation agencies must evolve beyond traditional infrastructure management to become active participants in the connected vehicle ecosystem. These expectations have profound implications for INDOT's organizational structure and capabilities.

**3.2.3.1 Targeted Infrastructure Deployment States.** should adopt strategic deployment strategies, focusing on accident-prone intersections, highway corridors, and mid-block pedestrian crossings rather than attempting uniform statewide coverage.

**3.2.3.2 Data-Sharing for Enhanced Safety.** Infrastructure-to-vehicle (I2V) communication enables real-time feedback loops that are especially valuable in congested urban environments and hazardous road conditions. However, uncertainty in traffic light prediction remains a challenge that requires improved algorithms and standardized communication protocols.

**3.2.3.3 Public-Private Partnerships.** State DOTs must align infrastructure priorities with OEM needs through collaboration. Revenue-based models, such as connected tolling systems, subscription-based advanced driver assistance systems (ADAS) services, and smart parking solutions, offer business cases that incentivize both sides to co-invest in deployment.

### 3.2.4 Strategic Challenges and Industry Positioning

The regulatory and competitive landscape creates complex dynamics that influence deployment timing and investment priorities. Understanding these forces helps position Indiana's initiatives for maximum impact and industry alignment.

**3.2.4.1 Regulatory Uncertainty.** Despite the FCC allocation of the 5.9 GHz spectrum to V2X, NHTSA has not yet issued a deployment mandate. This regulatory gap, combined

with differing state-level strategies, creates inconsistent progress nationwide. Some states, such as Texas and Florida, are moving aggressively, while others remain hesitant due to funding and political constraints.

**3.2.4.2 Shift Toward Business-Oriented Models.** This expert emphasized that OEMs prioritize applications with clear revenue streams. Automated tolling, connected parking, and ADAS subscription models are among the most viable. By bundling V2X into premium driver assistance packages, OEMs can offset deployment costs and secure consumer adoption.

### 3.2.5 Collaboration and Policy Environment

The expert’s perspectives on stakeholder collaboration reveal both opportunities and requirements for effective public–private partnership in CAV deployment. These insights suggest specific approaches INDOT should consider for engaging industry partners.

**3.2.5.1 State DOT Incentives.** Public safety remains a critical motivator for DOT investment. Cities such as Chattanooga have successfully used pedestrian fatality reduction as justification to secure USDOT Smart grants. Federal incentives will remain central to accelerating deployments, especially in states without a strong private sector pull.

**3.2.5.2 Mandates and Business Cases.** Mandates are likely to follow proven business cases. This expert noted that National Highway Traffic Safety Administration’s (NHTSA) Vision Zero and five-star safety ratings could increasingly depend on connectivity-based applications, creating a competitive incentive for OEMs to invest in V2X. Without such regulatory or rating pressures, large-scale deployment will remain slow.

This expert’s perspective underscores the dual challenge of technical readiness versus economic viability. While the sensor, communication, and edge computing technologies are mature, large-scale adoption depends on developing sustainable business models and aligning infrastructure investment with OEM incentives. For INDOT, the key lessons are clear:

- Prioritize high-risk intersections and corridors for incremental deployments.
- Leverage federal funding and smart city grants as catalysts.
- Explore revenue-based applications (tolling, parking, subscriptions) that create financial sustainability.
- Position Indiana as a collaborative testbed where industry and government share risks and benefits.

## 4. TECHNOLOGICAL AND INFRASTRUCTURE EVALUATION

### 4.1 Roadside Units (RSUs)

#### 4.1.1 Concept of Roadside Units

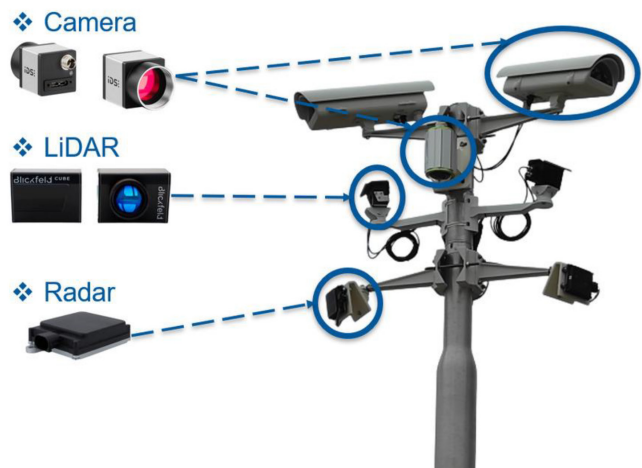
RSUs represent the physical backbone of connected vehicle ecosystems, serving as critical communication nodes that bridge the gap between individual vehicles and centralized traffic management systems. These installations, strategically positioned

along highways and arterial corridors, have evolved far beyond simple communication relays to become sophisticated sensing and computation platforms that enable real-time traffic optimization, safety applications, and environmental monitoring.

Modern RSUs integrate multiple functions within a single infrastructure element, as shown in Figure 4.1. A detailed classification is represented by Table 4.1. They facilitate Vehicle-to-Infrastructure (V2I) and Vehicle-to-Everything (V2X) communication protocols while simultaneously hosting advanced sensor arrays that capture comprehensive roadway data. This dual role, as both communication hub and perception platform, positions RSUs as essential components for enabling the sophisticated coordination required by connected and automated vehicle operations (Klein, 2024).

#### 4.1.2 Sensor Technologies for RSUs

To effectively support sensing and perception, RSUs are equipped with a variety of sensors that capture real-time data on traffic flow, roadway conditions, and potential hazards.



**Figure 4.1** A RSU Example (de Borba et al., 2023; Attribution 4.0 International CC BY 4.0 Deed).

**TABLE 4.1**  
**In-Roadway and Over-Roadway Mounted Sensors (Klein, 2024).**

In-Roadway Technologies (Intrusive)		Above-Roadway Technologies (Non-Intrusive)	
Inductive loop	Active	Video detection systems	Passive
Magnetometer	Passive	Microwave:	
Magnetic sensor also referred to as a magnetic detector	Passive	• Presence-detecting radar	Active
		• Doppler sensor	Active
		Passive infrared	Passive
		Lidar	Active
		Acoustic	Passive
		Ultrasound	Active
		Technology combinations	Active and passive

TABLE 4.2  
Traffic Sensor Selection Criteria (Klein, 2024).

Sensor Selection Dependencies	Types of Data Sensors Provide
Data categories required for the application <sup>a</sup> .	Flow rate, lane occupancy, and density.
Data accuracy and confidence interval.	Count, presence, and passage.
Number and types of vehicle classes to be detected.	Speed of individual vehicles and vehicle platoons by lane or roadway direction.
Life-cycle cost inclusive of sensor hardware and software, installation, training, and maintenance.	Vehicle class based on length, height, or image recognition.
Weather and climate in which the sensor will operate.	Queue lengths.
Road geometry and condition.	Approach flow profile.
Nighttime lighting requirement.	Approach stops.
Overhead mounting availability.	Time and spatial headways.
Vendor support.	Link travel time.
Agency preferences and culture including restrictions on pavement destruction or overhead mounting.	Wrong-way vehicles.
Availability of appropriate data transmission media.	Origin–destination pairs. Incident alarms.

<sup>a</sup>For example, incident detection through traffic flow parameter measurement, traffic signal actuation by means of lane-by-lane vehicle detection, or toll collection through vehicle classification and weight measurement.

The selection of sensors is guided by multiple performance factors, including:

- **Accuracy and Resolution:** ensuring precise detection and differentiation of vehicle types and roadway events.
- **Sensitivity:** the ability to detect small variations in measured parameters.
- **Sensing and Data Range:** the minimum and maximum distances or values captured.
- **Frequency and Responsiveness:** determine how quickly the system can react to dynamic roadway conditions.
- **Interface and Integration:** compatibility with communication protocols and back-end systems.

Additional considerations, listed in Table 4.2, include environmental robustness, nighttime performance, mounting feasibility, and life-cycle cost efficiency. A wide spectrum of data can be collected, such as traffic density, vehicle classification, queue lengths, and speed profiles. These capabilities make RSUs indispensable for supporting CAV operations.

## 4.2 Common Sensors

The deployment of CAV infrastructure relies heavily on sensing technologies integrated into RSUs and Virtual Roadside Units (vRSUs). These sensors provide critical perception data that enables traffic monitoring, incident detection, and cooperative safety applications. Commonly used sensor technologies

include camera/video systems, LiDAR, and radar, each with distinct advantages and limitations.

### 4.2.1 Camera and Video Detection Systems

Camera and video detection systems (VDS) capture high-resolution visual data and are widely adopted in traffic monitoring due to their cost-effectiveness and ability to provide rich contextual information. They are capable of covering wide fields of view, supporting multiple downstream tasks such as vehicle classification, lane occupancy monitoring, and incident detection. The non-intrusive installation further enhances their appeal for large-scale deployment.

However, cameras face performance challenges under adverse conditions such as low lighting, glare, and inclement weather. Occlusion of vehicles or objects reduces reliability, while the high processing demands necessitate powerful edge-computing hardware and robust data bandwidth. Privacy concerns and the need for frequent calibration and maintenance are also significant drawbacks that must be managed in operational environments.

### 4.2.2 LiDAR Sensors

LiDAR technology offers a highly accurate three-dimensional (3D) perception of surroundings, independent of lighting conditions, and is robust in low-light or foggy environments. This makes it well-suited for precise localization, vehicle classification, and advanced traffic management applications. Additionally, LiDAR is associated with reduced privacy concerns compared to video-based systems, since it does not directly capture identifiable visual data.

Table 4.3 summarizes the common specifications of commercially available and emerging LiDAR sensors currently considered for deployment in transportation infrastructure and CAV applications. Traditional spinning LiDARs, such as the Velodyne VLP-16 “Puck” and Velodyne HDL-64E, are widely deployed in research and smart city pilot projects. These sensors offer a 360° horizontal field of view, making them suitable for applications requiring comprehensive environmental coverage. Recent developments in solid-state technology, represented by Innoviz and Cepton, focus on scalability and cost reduction. These sensors eliminate moving parts, enhancing durability and reliability for large-scale deployments. Despite its advantages, LiDAR remains constrained by high acquisition and operational costs, significant computational requirements, and a limited vertical field of view. Mechanical components within certain LiDAR systems also pose reliability concerns over long-term operation.

Recent deployments highlight their value for smart intersection management. For example, Chattanooga, Tennessee, has executed one of the largest LiDAR-enabled traffic management programs in the nation, covering 12 intersections initially, with expansion planned to more than 120 intersections under a \$2 million citywide contract. Similarly, Murray, Utah, piloted a LiDAR-controlled intersection system, focusing on large-vehicle detection and addressing limitations caused by shadows and weather interference.

TABLE 4.3  
Common Specifications for Deployments.

LiDAR Sensor (Manufacturer)	Type	Max Range (m)	Resolution / Channels	FOV (H × V)	Data Rate (pts/sec)	Power (W)
Velodyne VLP-16 “Puck”	Spinning multi-beam (mechanical)	~100	16 channels (~0.2° vertical step)	360° × 30°	300k	8
<b>Velodyne HDL-64E</b> (legacy high-end)	Spinning multi-beam (mechanical)	~120	64 channels (0.4° vert, 0.08°–0.35° horizontal)	360° × 26.8°	1.3M (Single return); up to 2.2M (dual)	~60
Ouster OS1-64 (Gen 2)	Spinning multi-beam (digital)	~120 (80% reflectivity)	64 channels (±0.35° vert, 1024– 2048 pts/scan horiz)	360° × 45°	up to ~1.3M	12–15
Innoviz Two (Innoviz)	MEMS solid-state scanning	~150–200 (10% refl.)	720 (H) × 100 (V) pixels @ 15Hz (equiv. ~100k pts)	100° × 30°	up to 600k	5–10
Cepton Vista-P (Cepton)	Hybrid solid-state (micro-motion)	~100 (10% refl.)	1280 × 480 px @ 20Hz (aggregated)	120° × 30°	up to 1.3M	~8
SICK LMS511 (2D Scanner)	Single-plane laser scanner	~80 (10% refl.)	N/A (single layer, 0.5° res)	190° × 0°	up to 50 (HZ)	20 W

#### 4.2.3 Radar Sensors

Radar remains a reliable and cost-effective option for CAV-related sensing, particularly valued for its robustness across lighting and weather conditions. It offers long-range detection capabilities, reliable speed and range measurements, and low bandwidth requirements, making it suitable for continuous highway monitoring. Radar systems are also privacy-friendly, as they do not capture visual data.

However, radar suffers from low spatial resolution, limiting its ability to classify objects and capture detailed dimensions. Angular resolution constraints reduce accuracy in dense environments where multiple objects are in proximity. Additionally, radar is vulnerable to multipath effects and interference, which can produce ghost detections or false readings. Its limited field of view further restricts application in complex urban environments without sensor fusion support.

#### 4.2.4 Comparative Assessment of Sensor Modalities

As shown in Figure 4.2, each sensing modality offers unique strengths, making multimodal sensor fusion a necessity for comprehensive V2X infrastructure deployment. Cameras provide rich semantic and contextual data, yet their reliability is heavily dependent on favorable lighting and weather conditions. Conversely, radar ensures robustness and accurate velocity estimation in adverse environments but is limited by low spatial resolution, which hinders precise object classification. LiDAR bridges this gap by delivering high-fidelity, 3D mapping, though this precision comes with increased financial and computational costs.

Consequently, LiDAR was selected as the primary sensing modality for the RSU in this V2X framework due to its superior balance of spatial resolution and illumination of independence. As indicated in the comparative analysis, LiDAR significantly

outperforms radar and ultrasonic sensors in resolution and range, capabilities that are indispensable for the accurate segmentation and tracking of dynamic traffic participants in a 3D space. Furthermore, unlike passive visual sensors, which degrade performance in low-light scenarios, LiDAR maintains consistent reliability across day and night cycles. Although the technology entails higher implementation costs and exhibits sensitivity to heavy precipitation, these trade-offs are justified by the system’s requirement for precise, continuous, and high-resolution spatial data to support safety-critical V2X messaging.

### 4.3 Virtual Roadside Units

vRSUs are an emerging concept in ITS and vehicular networks. Unlike traditional roadside units that require dedicated physical infrastructure, vRSUs leverage software-based, cloud, or edge-computing solutions to provide similar communication and sensing functionalities. They are particularly relevant in vehicular ad hoc networks (VANETs) and in environments adopting 5G/6G-enabled V2X communication (Ferreira & d’Orey, 2012).

#### 4.3.1 Architecture of vRSUs

The architecture of vRSUs relies on a combination of direct short-range communication and cellular network-based communication. This dual-mode approach allows vRSUs to provide both ultra-low-latency safety services and scalable, cloud-enabled mobility applications (Sorrentino & Essery, 2019).

In the direct communication model, vehicles communicate with each other (V2V), with infrastructure (V2I), and with pedestrians (V2P) using the 5.9 GHz spectrum allocated to transportation. This mode supports real-time safety-critical

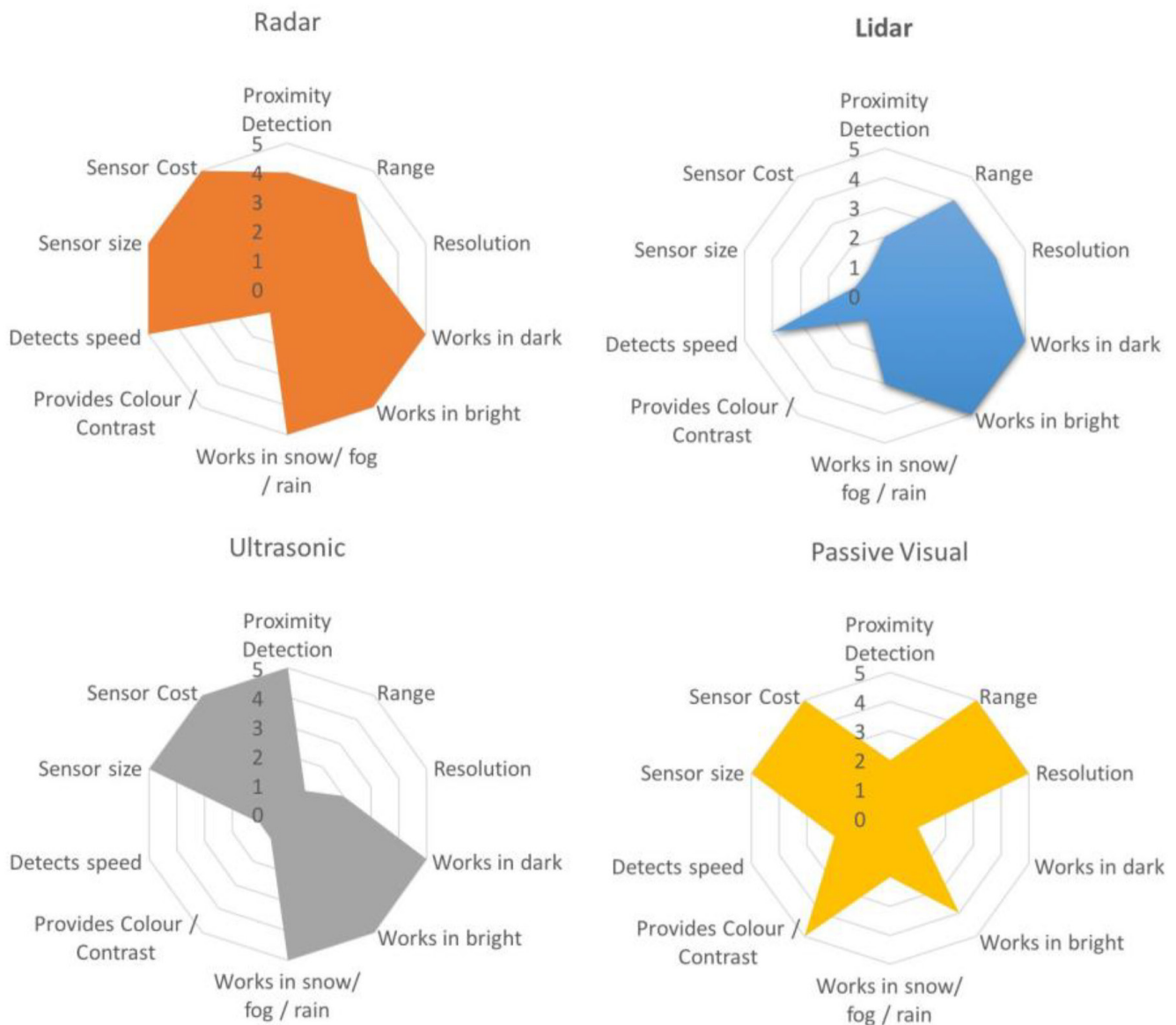


Figure 4.2 Comparison of Sensor Technologies (Barnard, 2016).

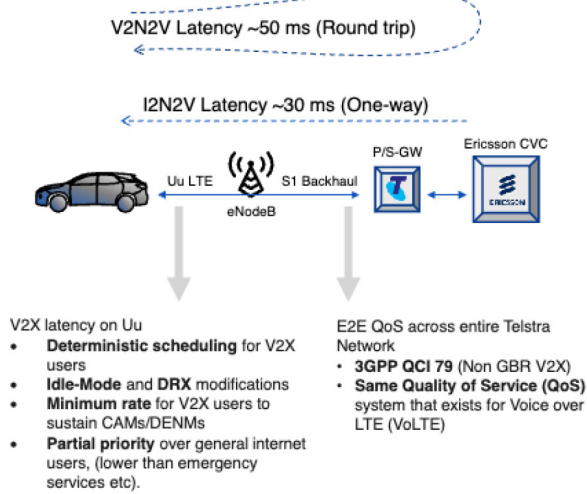
functions such as collision avoidance and protection of vulnerable road users (VRUs) through reliable, low-latency message exchange. In the network-based model, vehicles connect through licensed mobile operator networks (V2N), which interface with cloud or edge servers. This enables centralized management functions such as traffic signal timing, demand management, eco-routing, and system-wide data sharing. By leveraging cloud platforms, vRSUs function as “RSUs anywhere,” eliminating the need for extensive physical roadside deployments.

Figure 4.3 illustrates how the Uu interface in LTE/5G systems can be optimized for V2X applications. With deterministic scheduling and prioritization of V2X traffic, the system achieves latencies of approximately 30 ms (I2N2V, one-way) and 50 ms (V2N2V, round-trip), ensuring compatibility with many safety

applications. The diagram also highlights Ericsson’s vRSU architecture, where the V2X cloud replicates RSU functions by distributing traffic light timing, map information, and pedestrian status without physical RSUs.

The vRSU communication concept has two primary modes. The first one is direct communication independent of cellular networks, focusing on ultra-reliable safety services such as V2V collision warnings. The second mode depicts network-enabled communication, where V2N interactions leverage cellular infrastructure and cloud systems to support scalable traffic and demand management services. Together, these architectures demonstrate the hybrid role of vRSUs in future connected transportation networks, balancing the strengths of short-range and cellular-based communication to achieve both safety and scalability.

## Uu Optimized for V2X



## “Virtual RSU” Architecture

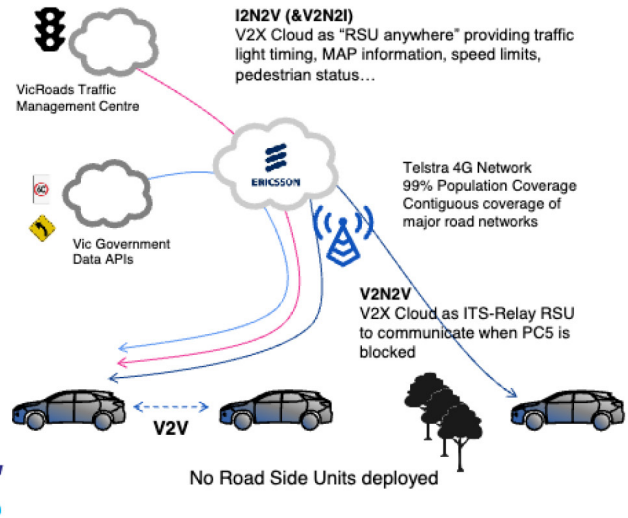


Figure 4.3 Uu Interface Optimization and Virtual RSU Architecture for V2X Communication (Sorrentino & Essery, 2019).

### 4.3.2 Applications and Pilot Deployments

Several U.S. State Departments of Transportation have initiated pilot projects demonstrating the potential of vRSUs:

- **Arizona DOT** in collaboration with the Maricopa Association of Governments (MAG) and Verizon, conducted a pilot project utilizing 5G Multi-access Edge Computing (MEC) to deploy vRSUs. This initiative aimed to deliver timely and potentially life-saving alerts to drivers without the need for extensive physical infrastructure (Verizon, n.d.).
- **Tennessee DOT** has explored the transition from DSRC to C-V2X technology (Khattak et al., 2023). This exploration includes considerations for vRSUs as part of their connected and automated vehicles investment and smart infrastructure initiatives (Wong et al., 2022).
- **Utah DOT** received a \$20 million grant to deploy V2X technologies across Utah, Colorado, and Wyoming. The project encompasses various deployment sites representing diverse demographics, jurisdictions, and transportation facilities, aiming to enhance safety and mobility through advanced communication technologies, including the implementation of vRSUs (FHWA, 2024).

## 4.4 Traffic Optimization for Signalized Corridors

The primary objective of this research is to develop planners and controllers that enable vehicles to interact effectively with infrastructure in mixed-traffic environments. By integrating CAV capabilities with existing traffic systems, the project aims to reduce congestion, lower energy consumption, and minimize emissions, contributing to a more sustainable future transportation system.

### 4.4.1 System Concept and Architecture

The traffic optimization framework is centered on a Cooperative Eco-Driving (CED) system, which integrates multiple components, including state machines, longitudinal control

models, and adaptive algorithms. V2V and I2V communications provide the foundation for cooperative adaptive cruise control (CACC), eco-approach, and departure maneuvers at signalized intersections.

- Figure 4.4a illustrates the CED concept, showing the interaction of V2V and I2V communication with roadside units (RSUs). The system manages vehicle approach to intersections through eco-driving strategies and CACC.
- Figure 4.4b details the system architecture, highlighting the role of state machines and longitudinal control models in governing role transition, operating modes, eco-approach and departure algorithms, and CACC algorithms.

### 4.4.2 Operation Mode

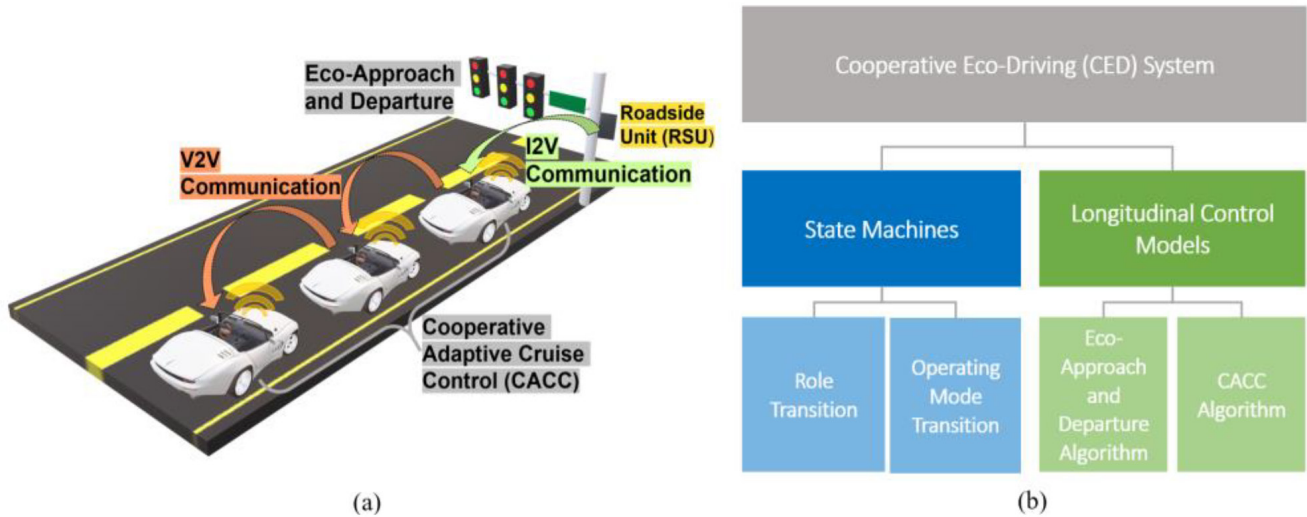
The system implements two primary traffic optimization modes designed to align vehicle movements with traffic signal phases:

**Speed-Up Mode:** This mode allows vehicles to accelerate as a group, crossing the intersection just before the end of the green phase. By coordinating vehicle speed, this mode ensures efficient throughput without compromising safety. Figure 4.5a depicts the coordinated speed control under the Speed-Up strategy, supported by mathematical formulations for acceleration profiles.

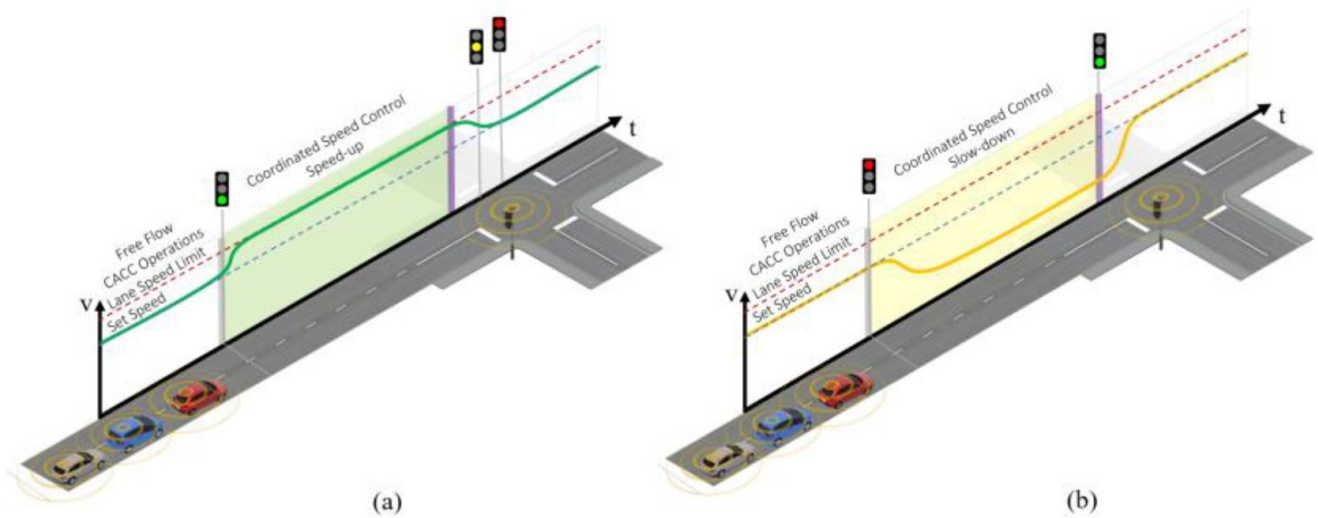
**Slow-Down Mode:** This mode enables vehicles to decelerate smoothly, gliding through the intersection immediately after the red phase ends. The controlled deceleration minimizes unnecessary stops, thus saving fuel and reducing emissions. Figure 4.5b demonstrates the Slow-Down strategy, highlighting how vehicles adjust speed dynamically to synchronize with signal timing.

### 4.4.3 System Validation and Performance Evaluation

The system was tested with different CAV penetration rates using real traffic data, including signal phase and timing (SPaT), flow patterns, and network configurations. Practical



**Figure 4.4** Illustration of a Cooperative Eco-Driving System (Wang et al., 2020).



**Figure 4.5** The Two Operation Modes for Traffic Optimization for Signalized Corridors System: (a) Represents the Coordinated Speed Control Under the Speed-Up Strategy; (b) Represents the Slow-Down Strategy (Goudy et al., 2019).

implementation involved testing with FHWA’s CARMA vehicle in Figure 4.6a at the Turner-Fairbank Highway Research Center test track, as well as Volvo heavy-duty trucks under real traffic conditions in Carson, California in Figure 4.6b.

The evaluation results demonstrate significant improvements in traffic efficiency and sustainability:

- Average travel time was reduced by 7%.
- Energy consumption decreased by 10%.
- Pollutant emissions were reduced by up to 56%.

By comparing the performance of the proposed cooperative eco-driving strategies against baseline models under varying CAV penetration levels, the experiment results confirm the robustness of the approach in mixed-traffic environments.

#### 4.5 Best Practice from Texas DOT

The Texas Department of Transportation (TxDOT) has advanced one of the most comprehensive Connected Freight Corridor initiatives in the United States, focusing on the Texas Triangle (Figure 4.7), which links Dallas–Fort Worth, Austin, San Antonio, and Houston. This region contains nearly three-quarters of Texas’s 27 million residents and is projected to grow to 39 million by 2040. It is a critical freight hub, with seven of the top 25 national freight bottlenecks and 11 of the top 20 most congested roadway sections located within the corridor. Freight tonnage is expected to double between 2010 and 2040, with two-thirds transported by truck. Additionally, Texas leads in cross-border trade, exceeding the combined values of

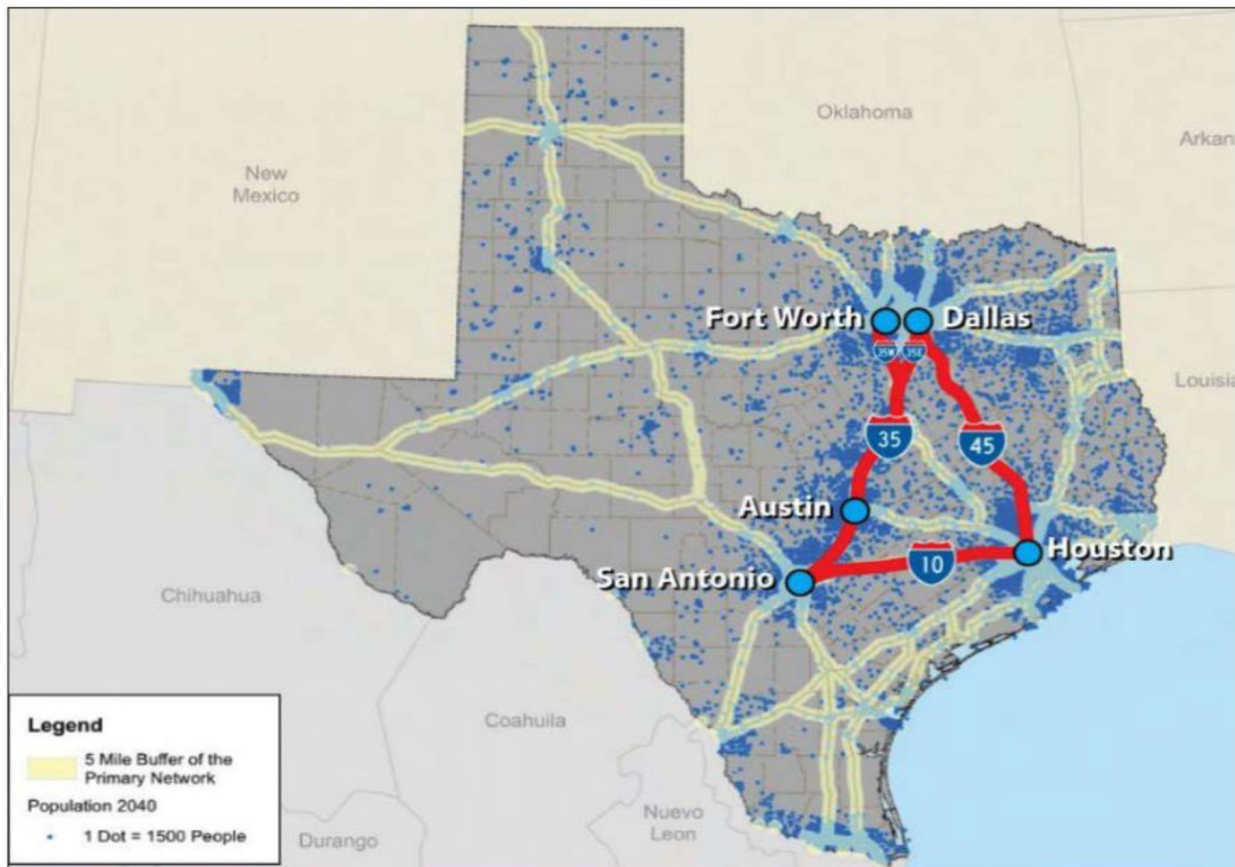


(a)



(b)

**Figure 4.6** The System Validation With (a) FHWA CARMA Vehicle (test track) (Wu et al., 2021) and (b) Volvo Heavy-Duty Truck (Real Traffic) (Wang et al., 2019).



**Figure 4.7** Texas Connected Freight Corridors (TxDOT, 2017).

California, Michigan, North Dakota, and Arizona (TxDOT, 2017), as shown in Figure 4.8. These factors have elevated the Texas Triangle as a national priority for connected freight solutions.

#### 4.5.1 Vision and Objectives

The Texas Connected Freight Corridors program seeks to promote economic efficiency and safety for commercial freight

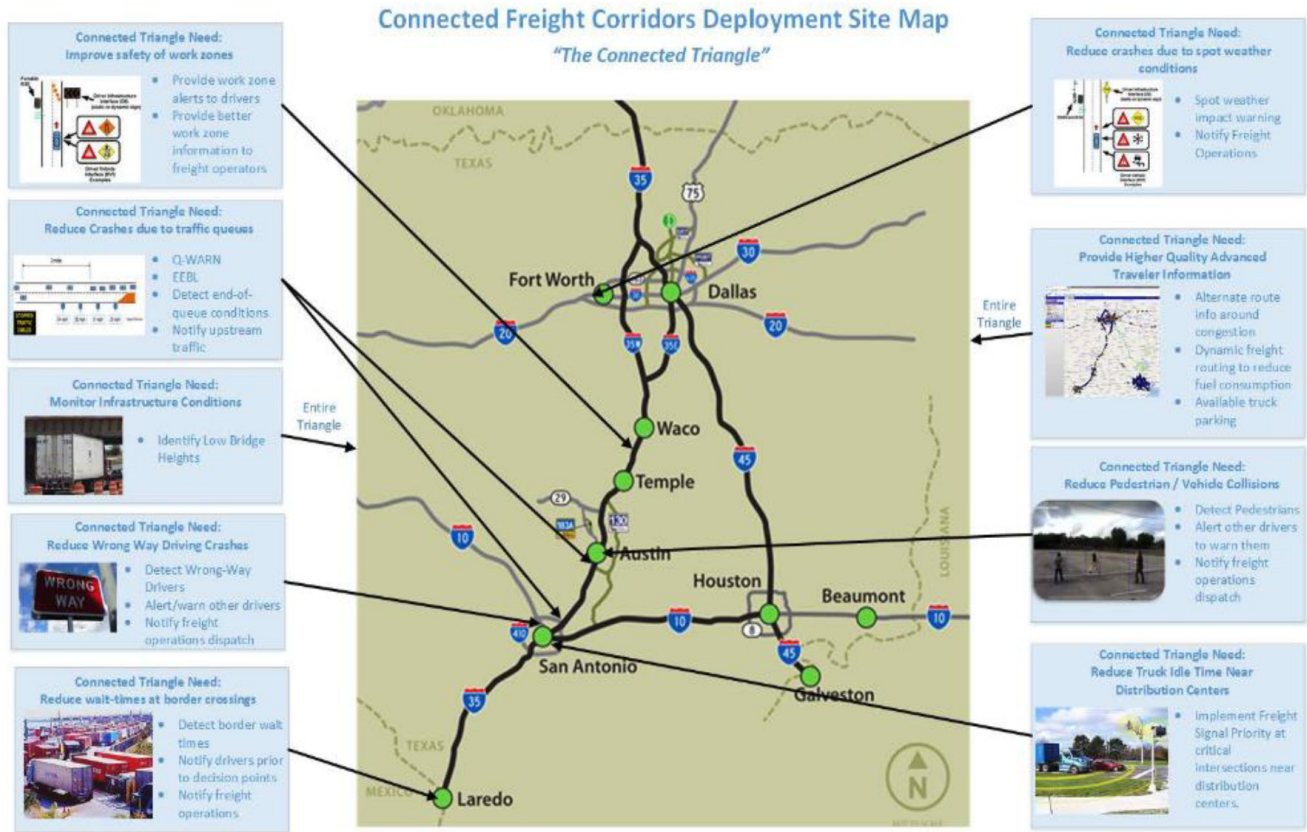


Figure 4.8 Connected Freight Corridors Deployment Site Map (TxDOT, 2017).

vehicles, followed by passenger vehicle benefits. Its strategy emphasizes “Day-One” benefits through the use of aftermarket devices, integration with existing on-board technologies, and the minimization of infrastructure costs for state and local transportation agencies. The long-term objective is to create a sustainable connected vehicle environment across the 865-mile Texas Triangle that supports both V2V and V2I safety and mobility applications.

#### 4.5.2 Stakeholder Partnerships

Partnerships have been essential to the program’s development. Public agencies formed a Concept of Operations Review Panel to guide framework design, while freight companies contributed to ensuring that commercial fleet operations were addressed in the deployment strategy. Collaborative efforts extended to universities, metropolitan planning organizations, and local municipalities, creating a multi-jurisdictional and cross-sector governance structure.

#### 4.5.3 Technology Investments and Pilot Projects

The program has leveraged significant regional technology investments to accelerate adoption. TxDOT conducted connected vehicle testing in San Antonio, with emphasis on in-vehicle signing and over-height detection systems. The I-35 Connected Work

Zone facilitated advanced data collection and integration, while truck platooning demonstrations highlighted the potential of SAE Level 2 automation for freight efficiency.

#### 4.5.4 Deployment Timeline and Organizations

The initiative was structured into three phases as shown in Figure 4.9:

- Phase 1: High-level design and planning (2019–2020).
- Phase 2: Detailed design and testing (2020–2023).
- Phase 3: Operations and self-evaluation (2023–2024).

Oversight and coordination were provided through a multi-layered organizational framework, including USDOT, TxDOT, regional partners, and local governments. This structured approach ensured continuity and accountability across the project lifecycle.

#### 4.5.5 Connected Vehicle Applications

The corridor deployment aligned with the USDOT focus areas and included a range of applications, both mature and emerging. Examples include:

- Advanced traveler information systems and eco-dynamic routing;
- Work zone, pedestrian crossing, and animal crossing warnings;

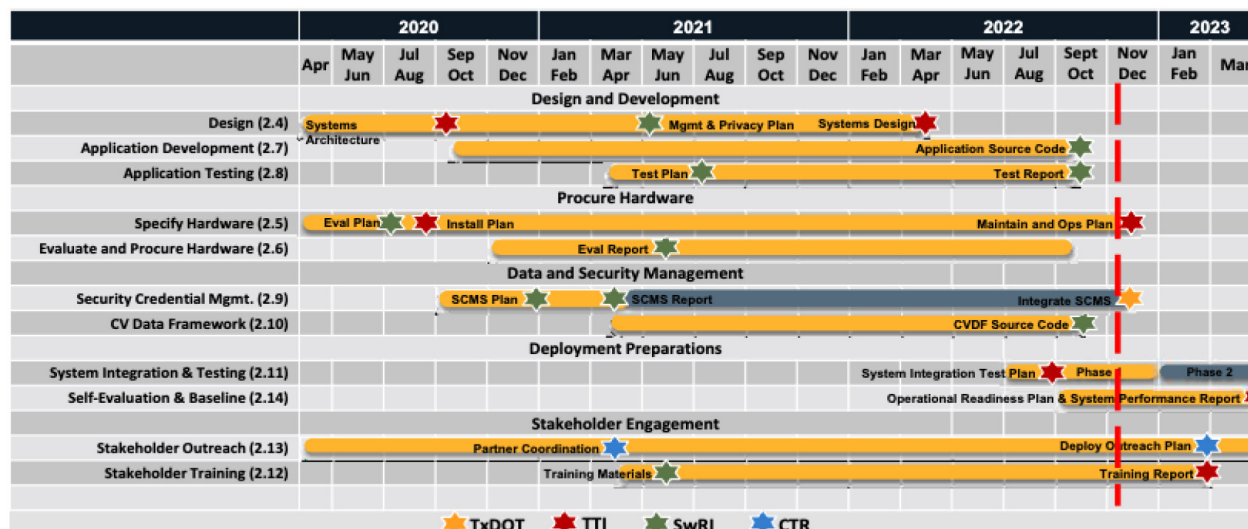


Figure 4.9 Connected Freight Corridors Timeline (Texas Department of Transportation, 2022).

- SPaT applications for bicycle and pedestrian safety;
- Freight applications such as truck parking availability, border wait-time monitoring, and truck platooning;
- Rural-focused solutions including low-bridge detection, traffic queue warnings, road weather monitoring, and wrong-way driving alerts.

The details are indicated by Table 4.4.

## 5. ORGANIZATIONAL RESOURCE ASSESSMENT

This chapter reviews how state and local agencies structure, fund, and manage CAV initiatives, highlighting implications for Indiana. Case studies from Florida, Minnesota, and Chattanooga illustrate diverse pilot deployments ranging from

large-scale corridor systems and autonomous shuttle pilots to Vision Zero safety projects using LiDAR analytics. Interviews with experts from Kentucky and Minnesota reveal organizational realities: lean staffing models, cybersecurity boundaries between traffic operations and IT, challenges of sustaining hardware deployments, and reliance on federal funding streams to mitigate budget risks. Common lessons emphasize the need for clear governance structures, standardized controller and data management practices, and carefully phased deployments to avoid stranded assets. Together, these insights underscore that technical readiness must be matched by institutional capacity, funding strategies, and cross-agency coordination to ensure long-term scalability of CAV infrastructure.

TABLE 4.4  
List of Connected Vehicle Applications (TxDOT, 2022).

USDOT Focus Areas	Proposed Applications		Proposed Locations
Multimodal ICM	Advanced Traveler Information System	Mature	IH35/SL340, Waco
	Eco-Dynamic Routing	New	IH35/SL363, Temple
	Work Zone Warnings	Mature	IH35/SH130, Austin IH30
CV at Pedestrian Crossings	Pedestrian/Animal Warning	New	IH35 in Austin
	SPaT Corridor for Improved Ped/Bicycle Safety	New	Riverside Dr., Austin
Unified Fare Collection/Payment System	Truck Parking Availability/Reservation	New	Rest Areas, IH35
Freight Community System	Border Wait Times	Mature	IH35, Laredo
Connected Communities	Truck Signal Priority	Mature	IH35, San Antonio
Infrastructure Condition Assessment	Low Bridge Height Warnings	New	IH35, IH45
Rural Technologies	Traffic & Road Info for Truck Platooning	New	IH35, IH45
	EEBL Alerts from Trucks Ahead	Mature	Austin/ San Antonio
	Traffic Queue Warnings	Mature	IH35, IH45, IH10, IH30
	Road Weather Warnings	New	IH35
	Wrong Way Driving (WWD) Alerts	Mature	San Antonio

## 5.1 Florida DOT (FDOT) Pilots

### 5.1.1 THEA Tampa Connected Vehicle Pilot

The THEA Tampa Connected Vehicle Pilot (Intelligent Transportation Systems Joint Program Office [ITS JPO], 2021a; FDOT, 2025) aims to improve safety and mobility in downtown Tampa by operating production V2X applications. The deployment, equipped with approximately 1,000 vehicles and 46 roadside units, began with DSRC and was upgraded to dual DSRC/C-V2X to support collision warnings, transit signal priority, and wrong-way entry alerts. Funding derived from the USDOT Connected Vehicle Pilot grant at about \$17 million, with local match, with additional technical support from the USDOT ITS JPO on spectrum sharing (ITS JPO, 2024). Field operations validated priority and hazard-alert workflows while revealing that RSU maintenance, firmware governance, and lifecycle management are the dominant recurring costs, which indicates that INDOT should plan asset governance, preserve DSRC and C-V2X compatibility, and formalize procedures for signal-controller integration and backhaul monitoring.

Particularly for Tampa Connected Vehicle Pilot Deployment (CVPD) in Figure 5.1, the focus is on vehicle applications and receiving positive feedback. The deployment formed part of three pilot sites that together implemented a suite of connected-vehicle applications and total federal funding of about \$45 million, with Tampa focusing on reducing the risk of collisions related to wrong-way entry. A mobility study (ITS JPO, 2021b) with more than 1,000 private citizens ran for over 19 months during 2018–2020 and examined the functionality and impact of V2V and V2I applications delivered through a rear-view-mirror human-machine interface. A complementary survey study (ITS JPO, 2022) assessed customer satisfaction and reported feedback from about 384 participants: 79% found End-of-Ramp Deceleration Warning beneficial, 13% found Wrong-Way Entry useful with an approximately 90% false-alarm rate, and 39% found Forward-Collision Warning useful to avoid a collision. The CVPD, therefore, concentrated on vehicle applications and received positive feedback.

#### 5.1.2 I-4 FRAME Corridor

The I-4 FRAME initiative targeted corridor-wide adaptive operations and traveler information across the Tampa–Orlando corridor by integrating 77 miles of Interstate I-4 and 122 miles of parallel routes with 491 smart signals, a mix of freeway sensors, arterial RSUs, and centralized software that links travel



**Figure 5.1** Tampa Connected Vehicle Pilot Deployment (FDOT, 2025).

information to a control center (FDOT, 2025). The program was funded by an FHWA Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) grant of about \$11.9 million in 2019, together with FDOT funds and regional collaboration with FDOT Districts 5 and 7 and local agencies (FDOT, 2025). Outcomes demonstrated that uniform controller configurations and a common data layer are prerequisites for freeway–arterial data fusion and incident response. It is suggested to enforce controller standards, synchronize data pipelines, define corridor performance indicators, and align fiber and cabinet upgrades with phased V2X deployment.

#### 5.1.3 Pinellas County Smart Community

This connected-corridor deployment on State Road (SR) 60 and US 19 leveraged RSUs broadcasting SPaT and queue warnings to vehicles and integrated with intersection crash-prevention systems (FDOT, 2025). Funding came through an FHWA ATCMTD grant of about \$4.6 million in 2020, with additional state and county resources for deployment and maintenance (FDOT, 2025). Operations showed that SPaT quality, mapping accuracy, and latency depend on coordinated timing changes and configuration control, so it suggests adopting SPaT quality specifications, formal governance for MAP geofencing, and a change-management process that preserves broadcast integrity when timing plans are updated.

#### 5.1.4 SunTrax AV Test Facility

SunTrax serves as a 2.25-mile closed-course test track that provides high-speed wireless, smart sensors, a simulated city environment, and a simulation center for testing automated and connected vehicle technologies. Florida’s Turnpike Enterprise funds the facility at approximately \$42 million in state funds with public–private partnerships involving auto-tech companies for testing programs. The proving-ground environment accelerates validation prior to public-road pilots and highlights the need for clear cybersecurity, data-sharing, and intellectual-property terms, which recommend leveraging third-party proving grounds for pre-deployment testing and standardizing contract language for data ownership, security, and dissemination of results.

## 5.2 Minnesota DOT Pilots

### 5.2.1 TH-55 Connected Corridor

MnDOT equipped approximately 22 DSRC RSUs on traffic signals to broadcast SPaT, installed onboard units on snowplows for signal-priority requests, and supported V2I red-light-violation warnings with a focus on winter operations improvement (MnDOT, n.d.d). The effort was funded by the MnDOT CAV-X program as a state-funded pilot from 2018 to 2020 and was supported by the City of Minneapolis and Metro Transit, which provided intersection access and buses for testing. Cold-region operations emphasized enclosure, power, and mounting practices and required formal operating rules for

transit and emergency priority, recommending cold-weather RSU installation specifications, cabinet thermal management, and documented priority policies with partner agencies.

### 5.2.2 Autonomous Shuttle Pilots

MnDOT executed low-speed automated shuttle pilots in real-world environments, including downtown Minneapolis “Med City Mover” operations and a Rochester pilot at the Mayo Clinic, that implemented shuttle-to-traffic-signal communication using DSRC and wireless broadcast of data to a control center. Funding followed a local-state partnership model with MnDOT CAV Challenge support and local Destination Medical Center grants, together with in-kind support from shuttle manufacturers and FHWA research funds. Operations required trained attendants, detailed safety cases, and route designs that manage weather and visibility constraints, which suggests that INDOT should restrict pilots to defined use cases, require safety-management plans, and collect standardized service reliability and cost metrics.

### 5.2.3 Snowplow Driver Assist System

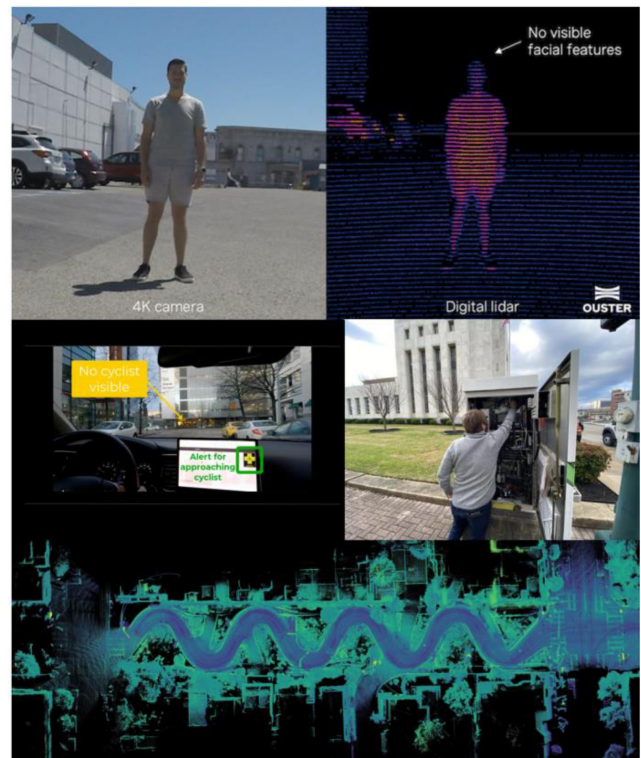
On the I-94 MnROAD test track and Twin Cities free-ways, MnDOT equipped a fleet of 8–10 snowplows with high-precision GPS, lidar, and head-up displays to support the driver in low visibility. The system is not a V2X broadcast platform but an infrastructure-assisted automation approach in which road data, including digital maps and delineators, guide vehicles in poor visibility and provide the groundwork for future connected winter-maintenance fleets. Funding combined an FHWA Road Weather grant with MnDOT research resources at a scale of about \$5 million in phased awards from 2015 through 2018 and included partnerships with 3M for enhanced markings and signs and with the University of Minnesota for human-factors research. Results indicated reduced workload when guidance accuracy and display usability met thresholds and identified digital-map curation as the dominant maintenance task.

### 5.2.4 Connected Corridor Planning

MnDOT conducted strategic planning for future V2X deployment on corridors, including I-94, by evaluating fiber needs, RSU placement, and potential applications such as queue warning, curve-speed warning, and rural intersection collision avoidance using V2I sensors. No large deployment is scheduled as of 2025, but detailed infrastructure plans are in place. Funding and coordination occurred through State Planning and Research with support from USDOT ITS Deployment Evaluation grants and collaboration with neighboring DOTs, including Wisconsin, to ensure corridor continuity.

## 5.3 City-Level Project from Chattanooga DOT: Vision Zero Safety Initiatives

Chattanooga DOT combined an Ouster lidar grid with Seoul Robotics’ perception software to understand pedestrian behavior and traffic patterns and to identify potential safety



**Figure 5.2** Vision Zero Safety Initiatives, a City-Level Project of Chattanooga DOT (Chan, 2022).

risks (Figure 5.2). A pilot at 12 local intersections achieved a 100% reduction in near-miss incidents on a high-risk city block, according to the University of Tennessee, which led the city to award Ouster a \$2 million contract to expand deployment to more than 120 intersections across Chattanooga. The project demonstrates that fixed-site digital LiDAR can deliver privacy-preserving detection with actionable safety analytics.

## 5.4 Interview Insights of an Expert from Kentucky Transportation Cabinet (KYTC)

### 5.4.1 Organizational Structure and Staffing

KYTC’s CAV work is housed in the Innovation Group within the State Highway Engineer’s Office, alongside Transportation Systems Management and Operations (TSMO) and Research (which coordinates federally funded research programs). From the expert information, this placement allows CAV to touch planning, operations, and research without being siloed in any single functional division. At the statewide level, KYTC is a cabinet agency that reports to the Governor and is organized into four departments: Highways, Aviation, Motor Vehicles, and Rural and Municipal Aid. Most CAV and ITS efforts reside within the Department of Highways. Regionally, Kentucky operates 12 districts, each functioning as a “mini cabinet” that manages maintenance, operations, and capital delivery locally.

Staffing for CAV is intentionally lean. One full-time position leads day-to-day CAV efforts, drawing ad-hoc support from

TSMO, planning, and research as projects arise. The CAV role also interfaces with the State Transportation Innovation Council (STIC)/Everyday Counts process, which helps align innovation priorities across the Cabinet. As initiatives and funding ebb and flow, supporting staff are reassigned accordingly.

#### 5.4.2 Hardware and Infrastructure

CAV hardware is deployed project-by-project and subsequently integrated into the broader ITS estate. RSUs are a primary asset type for CAV pilots. Kentucky operates two Traffic Management Centers (TMCs); one is evolving into the central manager for statewide ITS devices, and RSUs are expected to be operated and maintained from this hub. Deployment density reflects Kentucky's geography: metropolitan areas (Louisville, Northern Kentucky, and Lexington) drive most ITS/CAV needs, while rural regions deploy more selectively. Kentucky passed a platooning law in 2018, but, to date, the state has not received active platooning requests, underscoring the measured pace of market demand.

Recurring operational reality is the boundary between Traffic Operations (which runs a cybersecurity-hardened, closed operational network for signals, DMS, and other field devices) and central IT. This boundary preserves reliability for safety-critical systems but complicates cross-enterprise integration when CAV assets (e.g., RSUs) join the network. A designated integrator/mediator function has therefore become important to balance operational independence with system-level interoperability.

#### 5.4.3 Software and Data Management

The expert indicates that the data governance is split but converging. Today, ITS-generated data (e.g., RWIS, RSUs) is primarily managed by Operations and Maintenance because it directly supports field operations (e.g., winter maintenance). By contrast, enterprise or third-party datasets that inform planning, pavement, asset management, or safety analytics may flow into central IT's data warehouse. While no single unified platform currently exists, KYTC is trending toward an in-house foundation enhanced by artificial intelligence (AI)-enabled tooling, with the ATMS likely to serve as the integration locus as governance is formalized. The expert noted he would follow up with specifics as the platform direction is finalized, reflecting that this is an active workstream rather than a settled design.

Organizational silos, both regional and functional (Traffic Ops vs. IT), remain the biggest inhibitor to a unified data and device management approach. Formalizing interfaces, roles, and trust boundaries (especially for cybersecurity on the operations network) is the primary prerequisite to an integrated CAV/ITS data environment.

#### 5.4.4 Budget and Funding

The expert addressed that KYTC leverages a mixed federal funding portfolio to advance CAV and related ITS work:

- FHWA Accelerated Innovation Deployment (AID) Demonstration
- ATCMTD grants

- STIC funds (about \$100K) for innovation pilots and processes
- SPR funds for research and university partnerships (e.g., AV acceptance studies with the University of Louisville)

A flagship planning effort, the I-64 CAV corridor, was funded at \$750,000 through the State Highway Plan using National Highway System (NHS) dollars. Because the amount exceeded the typical \$250K cap on the planning roster, it was procured via an open solicitation. A standard state match (about 20%) applies. KYTC's Planning unit typically delivers 8–10 studies per year, and the I-64 effort was aligned with that workflow, albeit at a larger scale. In practice, planning funds are often the most practical on-ramp for CAV initiatives, as they face less competition from preservation and expansion demands than construction dollars.

#### 5.4.5 Partnerships and Projects

KYTC maintains active collaborations with the University of Louisville and its Transportation Research Center on topics like AV public acceptance. Given Kentucky's strong automotive footprint (e.g., Toyota and Ford operations), the Cabinet designed a three-part stakeholder engagement plan for the I-64 corridor (local agencies, industry, and public). However, political timing has delayed broad stakeholder outreach. The I-64 study has completed Operations and Maintenance planning and is in environmental review; upcoming work includes scoping enabling legislation/policy (e.g., following-distance for platoons) and exploring P3 feasibility, consistent with national practice on similar corridors.

#### 5.4.6 Key Challenges and Lessons Learned

**5.4.6.1 TSMO as a Foundation.** Kentucky has formally adopted the TSMO model and is aligning its operations practice with AASHTO's Transportation Operations Manual (TOM). This provides common vocabulary for operations, incident management, and connected vehicle integration.

**5.4.6.2 Capacity and Role Clarity.** A **single full-time CAV lead** can coordinate effectively with research, TSMO, and planning; however, sustained progress will ultimately require additional capacity and clearly codified responsibilities at the Traffic Ops/IT interface.

**5.4.6.3 Network Governance and Cybersecurity.** The **closed operations network** is mission-critical and must remain reliable; integrating CAV/ITS data paths without eroding that reliability requires explicit governance, shared cybersecurity standards, and carefully managed cross-domain interfaces. **Mediator roles** (with authority) help resolve stalemates.

**5.4.6.4 Urban–rural Asymmetry.** Kentucky's ITS/CAV footprint grows fastest where benefits concentrate (Louisville, NKY, Lexington). Rural areas will continue to prioritize targeted deployments that show clear O&M or safety returns.

**5.4.6.5 Policy Headwinds.** The **AV framework bill** passed the legislature, was **vetoed by the Governor**, and then

**overridden**, creating a careful posture inside the Cabinet while regulations are developed. The political dynamic temporarily slowed the I-64 corridor’s stakeholder engagement and public messaging, illustrating how policy timing can affect program momentum even when technical work progresses.

## 5.5 Interview Insights of an Expert from MnDOT

### 5.5.1 Organizational Structure and Staffing

MnDOT’s CAV office grew out of the ITS team around 2018–2019 and now sits under the TSMO office within the Operations Division. While this placement matches how USDOT often positions CAV, the team views its work as research- and innovation-oriented rather than system-wide deployment, and therefore not the best long-term fit under TSMO. Internal conversations are active about a possible realignment that better reflects the office’s innovation role.

The team is roughly ten staff covering a director role, senior engineers, project managers, policy/engagement leads, and a maintenance-focused position. Several members hold commercial driver’s licenses (CDLs) and bring hands-on fleet and snowplow experience, which helps in applied testing. There is an ongoing internal discussion about structural adjustments to make the office’s mandate clearer and to reduce friction with broader operations.

### 5.5.2 Hardware and Infrastructure

Historically, MnDOT deployed RSUs using both DSRC and V2X in pilots (e.g., Mid-City Mover: ~14 signals for one year; White Bear Lake: single signal). Performance was intermittent, and a vendor later went bankrupt, leaving devices unserviceable and even physically hazardous (e.g., mast-arm removals via contract). MnDOT consequently removed RSUs where there was no long-term need and now requires removal after pilots unless another unit (e.g., TMC or Electrical Services) agrees to maintain them.

The expert clarified that the virtual RSUs have not been implemented to date; one project may explore the idea, but there is no active plan. Strategically, the team is cautious about large-scale V2X infrastructure given weak OEM integration (few vehicles with onboard units) and the risk of stranded assets. Where high-risk deployments are justified, the preference is to use federal funding rather than state funds. On roadway sensing, MnDOT primarily uses pan-tilt-zoom (PTZ) cameras today (e.g., truck-parking initiatives); it is moving away from loops, and while future bridge-hit prevention could involve radar and LiDAR, cameras remain the mainstay.

### 5.5.3 Software and Data Management

The expert indicates MnDOT typically does not store raw CAV data. Consultants/technology partners host the data and provide analyses/dashboards. This approach minimizes retention due to Minnesota’s Data Practices Act (privacy risk and carrying cost). Some software functionality and vehicle-side

algorithms remain inaccessible due to vendor intellectual property protections, which limit transparency into algorithmic updates and performance. MnDOT therefore emphasizes asking the right questions and reviewing visual/aggregate outputs rather than raw proprietary code or data. It is also clarified that enterprise IT is separate from MnDOT (a state-level IT agency). The CAV team is coordinating with that agency on a new data-aggregator project, but cross-agency processes introduce coordination challenges.

### 5.5.4 Budget and Funding

The CAV program receives state funds initiated by a 2018 executive order. The total annual program budget is \$6.8 million, of which \$4.3 million is typically programmed for projects. COVID and slow procurement cycles have historically made it difficult to spend down the annual project allocation, though the team is working to fully program funds in the current biennium.

Funding flows through internal programs like the CAV Challenge and Innovation Ideas programs, as well as direct research. Recent and planned investments include an ADAS-equipped snowplow (delivery expected Christmas 2026) for operational evaluation across MnDOT’s 800-vehicle snowplow fleet, and potentially a global test vehicle for AV/ADAS testing, though the latter faced internal pushback. The expert expresses that if programming continues to under-run, leadership may request a lower future budget to better match prioritization and sustain existing systems.

### 5.5.5 Partnerships and Projects

The expert explains that delivery of the project varies by scope and urgency: consultants, universities, and internal staff are all used. MnDOT often coordinates with its central research office for university-driven work but will deploy office funds to accelerate timelines when the academic research cycle is too slow.

The team maintains accessible project documentation (web content and two-page summaries) and places a strategic emphasis on turning pilot findings into usable outcomes for operations and safety. Past outreach to OEMs stalled, given unclear AV legal frameworks in Minnesota. Looking ahead, the team is interested in leveraging new opportunities, for example, cold-weather testing via TRC’s northern Minnesota site, and in low-cost safety tech such as automatic emergency braking for construction vehicles to reduce worker risk.

### 5.5.6 Key Challenges and Lessons Learned

The expert addresses the challenge as follows:

- **Structural fit and mission clarity:** The team’s research/innovation identity does not always align with an operations-centric TSMO framework, complicating priority-setting and messaging.
- **Hardware risk:** Earlier RSU deployments yielded limited/unstable results; vendor insolvency left stranded assets, reinforcing a cautious approach to V2X and a preference to use federal (not state) funds where risks are high.

- **Budget limitation:** Difficulty in fully utilizing the annual project budget due to slow procurement cycles, COVID-related delays, and limited internal capacity for project generation.
- **Lack of legislation support:** Industry partnerships are limited by the absence of AV legislation in Minnesota, which deters OEMs from engaging in pilots or deployments in the state.
- **Impact focus:** The team is explicitly exploring high-impact internal uses (e.g., advanced emergency braking [AEB] for construction vehicles, ADAS snowplows) where safety and operations benefits are immediate and demonstrable.

## 6. STRATEGIC ROADMAP FOR CAV DEPLOYMENT IN INDIANA

Indiana stands at a pivotal moment where technological maturity, regulatory clarity, and economic necessity have converged, making immediate strategic investment in CAV infrastructure not just feasible but essential. The preceding chapters have laid the evidentiary foundation for this plan by analyzing the successes and challenges of regional peers like Michigan, Ohio, and Minnesota; evaluating the maturity of critical infrastructure technologies, from physical RSUs to vRSU concepts and sensor modalities; and assessing the organizational prerequisites, including staffing, data governance, and funding models required to sustain these investments. This strategic roadmap represents the conclusion of the feasibility study, translating comprehensive research, stakeholder insights, and technological evaluations into an actionable deployment framework for the INDOT.

### 6.1 Strategic Foundation

#### 6.1.1 Vision of the Roadmap

The timing of this initiative is driven by the critical factors identified in this feasibility study. The first is technological readiness: The era of purely experimental testing is ending. Core technologies, including V2X protocols, advanced roadside sensing using LiDAR and radar, and edge computing, have matured to the point where they can reliably support safety-critical applications such as collision avoidance and queue warnings. Furthermore, the shift from a vehicle-first approach to an infrastructure-first approach enables infrastructure owners such as INDOT to deploy sensing assets that deliver immediate safety benefits to all road users, regardless of vehicle automation levels. The second factor is national and regional momentum: The regulatory landscape has stabilized with recent FCC spectrum rulings and the release of the USDOT's National V2X Deployment Plan, creating opportunities for coordinated industry action. With significant CAV investments already underway in neighboring states such as Michigan and Ohio, Indiana must aggressively pursue interoperability to ensure seamless cross-border mobility and capture available federal funding under the Infrastructure Investment and Jobs Act.

This roadmap is not a static directive, but a living framework designed to guide INDOT's investments and partnerships over the next decade. The strategic plan provides the structure

needed to navigate this transformation, ensuring that Indiana does not merely react to industry changes but actively shapes a transportation ecosystem that serves its specific economic and safety needs.

#### 6.1.2 Guiding Principles and Priorities

To ensure consistency across all initiatives, this roadmap is anchored by a clear vision and mission that aligns CAV deployment with Indiana's broader transportation goals. Every proposed pilot project, infrastructure upgrade, or partnership agreement is evaluated against its ability to deliver on this mission, prioritizing tangible benefits for Indiana residents and businesses over purely experimental innovations.

- **Safety:** Indiana will be a recognized leader in integrating CAV technologies to ensure safety. This commitment extends beyond reducing vehicle collisions to include protecting all road users, including pedestrians, cyclists, and construction workers. By deploying infrastructure-based safety applications, the state can address its most pressing crash scenarios while building public confidence in connected and automated systems.
- **Efficiency:** Efficiency defines the operational mission, fostering an integrated multimodal transportation system that utilizes connectivity and automation to enhance mobility and support the economy. Indiana's highway network carries a disproportionate share of national freight traffic, and even marginal improvements in throughput and travel time reliability translate into substantial economic benefits for shippers, carriers, and consumers. CAV technologies enable the maximization of existing roadway capacity and reduce fuel consumption through coordinated signal timing and vehicle movements.
- **Innovation:** Innovation ensures long-term competitiveness by leveraging Indiana's industry and research ecosystem to test, validate, and scale emerging CAV technologies before broader deployment. The state is home to major automotive manufacturers, a thriving logistics sector, and leading research institutions with deep expertise in transportation systems. By positioning Indiana as a living laboratory for CAV advancement, the state can attract investment, cultivate workforce expertise, and ensure that its transportation network remains at the forefront of technological progress.

### 6.2 Implementation Recommendations

#### 6.2.1 CAV Corridor Readiness: Prioritize Key Freight and Urban Corridors

As the crossroads of America, Indiana is uniquely positioned to advance CAV deployment by preparing its critical roadways to support connected automation. Given the central role of freight movement along corridors such as I-65 and I-70, these highways are prioritized for deployment and will be equipped with the necessary digital infrastructure to support multiple CAV use cases. Applications such as truck platooning show strong potential for these routes, offering the potential to significantly reduce fuel consumption and increase throughput without requiring physical expansion of roadway capacity.

Beyond the interstate network, the deployment of urban infrastructure in areas with the highest density of conflict points

also has a significant influence. Following the “infrastructure-first” model validated by pilots in Tampa and Chattanooga, INDOT can target high-crash intersections in metropolitan areas like Indianapolis for immediate deployments. Equipping signals with SPaT broadcasters and MAP (as intersection geometry) messages allows connected vehicles to anticipate signal changes, thereby reducing red-light violations and mitigating the “dilemma zone” risks that lead to severe intersection crashes. This urban focus ensures that the benefits of connectivity extend to pedestrians and transit users in dense environments.

Simultaneously, the state could position itself to accommodate autonomous vehicles by examining how V2X corridors can enhance AV performance. Infrastructure-supported connectivity not only improves autonomous vehicle safety and reliability but also creates opportunities for AVs to optimize traffic flow across the network. By providing real-time data on signal timing, roadway conditions, and surrounding traffic, V2X infrastructure reduces the computational burden on individual vehicles and enables more precise decision-making in complex driving scenarios. This symbiotic relationship between infrastructure and vehicle intelligence is particularly valuable at intersections, work zones, and other environments where sensor-based perception alone may be insufficient. As autonomous technology matures, corridors equipped with robust V2X communication will serve as proving grounds for increasingly sophisticated AV operations, positioning Indiana as a national leader in integrated transportation systems.

#### *6.2.2 Technology Integration: Expand V2X Deployments with Physical and Virtual RSUs*

The maturity of CAV technologies has shifted the focus from experimental testing to scalable integration, requiring INDOT to adopt both physical V2X RSUs and vRSUs. This approach uses physical V2X RSUs for safety-critical, low-latency applications such as collision avoidance, while leveraging commercial 5G cellular networks for latency-tolerant applications such as traveler information. To achieve cost-effective scalability, the roadmap also recommends integrating vRSUs technology to complement physical hardware. Unlike traditional infrastructure that requires power and maintenance at every pole, vRSUs are cloud-based software functions that deliver signal timing and regulatory data to vehicles via cellular networks.

This dual approach strategy allows INDOT to rapidly expand digital coverage across thousands of intersections and miles of roadway without the prohibitive capital expense of installing physical hardware at each location, thereby accelerating the timeline for statewide coverage.

#### *6.2.3 Workforce and Public Engagement: Build Internal CAV Workforce Training and Public Trust*

The CAV deployment cannot succeed without a skilled workforce to maintain it and a public that trusts it. The integration of intelligent transportation systems and IT demands a shift in expertise, requiring INDOT to develop training that bridges

traditional civil engineering with information technology and network management. This means traditional maintenance personnel must acquire proficiency in fiber optic networks, RSU configuration protocols, and/or cybersecurity practices. To secure this expertise, INDOT could establish a CAV workforce development program that systematically documents deployment experience and standardizes equipment specifications across districts. This ensures that successful strategies in one district are quickly replicated across the state, keeping the organization in step with the technology.

Equally important is building public understanding and acceptance of CAV technologies. INDOT will implement a comprehensive public engagement strategy that addresses common concerns about safety, privacy, and the role of automation on public roads. This strategy could include educational campaigns that explain how CAV infrastructure works and the benefits it provides, such as reduced crashes and improved traffic flow.

Community outreach events, particularly in areas selected for pilot deployments, will give residents the opportunity to ask questions and provide input before projects begin. For example, by publishing data from pilot projects, such as V2X intersection safety initiatives that prevent crashes and reduce pedestrian fatalities, the department can demonstrate tangible value and reinforce public trust.

#### *6.2.4 Research and Industry Collaboration: Partner with OEMs, Universities, and Suppliers*

Indiana’s successful navigation of the CAV transformation necessitates leveraging its comprehensive ecosystem to validate innovations and distribute implementation risks. INDOT could continue to utilize the Joint Transportation Research Program (JTRP) and strategic university partnerships as independent validators of emerging technologies. Prior to statewide deployment, all emerging technologies and innovations need to undergo rigorous testing protocols to verify their robustness, effectiveness, performance metrics, and interoperability standards. This validation serves as a critical safeguard, protecting state investments from unproven technologies while ensuring that deployment decisions are grounded in empirical evidence.

Effective CAV deployment depends equally on strategic engagement with OEMs and suppliers. These partnerships are essential throughout the deployment phase, both for small-scale pilot testing and for full-scale implementation. Vehicle modification for CAV capabilities requires deep technical collaboration with manufacturers that possess proprietary knowledge of vehicle architecture and communication protocols. Infrastructure modifications similarly require supplier expertise to ensure compatibility with evolving industry standards. Beyond technical considerations, these partnerships address fundamental economic realities: CAV deployment requires substantial capital investment and market development. Real-world operational data from connected vehicles will enhance infrastructure maintenance and planning while providing manufacturers with valuable deployment insights.

### 6.3 Implementation Phases

Recognizing that full CAV integration is a long-term evolution rather than a singular event, this roadmap organizes strategic actions into three distinct time horizons. This phased approach allows INDOT to build foundational capabilities before scaling complex deployments.

- **Phase 1 (2025-2027): Foundation and Pilots:** The immediate focus is on establishing the policy, organizational, and digital foundations. Actions in this phase prioritize “Day One” safety applications, targeted infrastructure pilots at high-risk locations, and the formalization of data governance and cybersecurity standards identified in the organizational assessment.
- **Phase 2 (2028-2030): Scaling and Interoperability:** As pilots yield performance data, the focus shifts to scaling successful technologies across broader corridors. This phase emphasizes regional interoperability with neighboring states (aligning with MAASTO region initiatives) and targeted infrastructure upgrades to support higher levels of vehicle automation and freight efficiency.
- **Phase 3 (2030+): Integration and Transformation:** In the mature phase, CAV technologies transition from standalone projects to standard elements of INDOT’s asset management and operations. This horizon envisions widespread deployment of cooperative automation features, full integration of V2X data into traffic management centers, and infrastructure capable of supporting advanced automated driving systems (ADS) operating in mixed traffic.

### 7. CONCLUSION AND FUTURE WORK

This study integrates literature and program review, structured stakeholder interviews, and targeted technical synthesis to build an Indiana-specific evidence base. Peer programs were analyzed for objectives, architecture, funding, performance, and institutional arrangements, while OEM and stakeholder perspectives were organized around infrastructure needs, technical constraints, regulatory context, and partnership opportunities. Technology assessments were framed by application requirements, including latency budgets for safety functions, field-of-view, and detection performance for perception, and data models aligned with production vehicle standards. The resulting analysis supports recommendations that can be phased by corridor, by intersection risk, and by organizational readiness.

The report delivers three outputs that guide implementation. First, it synthesizes the best regional practices and industry direction to distinguish what is feasible now from what requires further development. Second, it establishes a technical baseline that links priority applications to sensing and communications architectures with explicit attention to interoperability, security, and maintainability. Third, it defines an implementation framework that connects capital and operating investments to organizational capabilities, funding sources, and measurable outcomes for safety and mobility. Together, these outputs provide a basis for deciding where to pilot, where to scale, and how to manage assets and data over time.

Future work should convert these findings into a detailed CAV strategic plan for Indiana that balances safety, efficiency, and innovation. The next steps are to outline a phased implementation roadmap with immediate, near-term, and long-term actions and milestones.

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## About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1 — evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at [docs.lib.purdue.edu/jtrp/](https://docs.lib.purdue.edu/jtrp/).

Further information about JTRP and its current research program is available at [engineering.purdue.edu/JTRP](https://engineering.purdue.edu/JTRP).

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