



# PI-0373 Caltrans Roadway Digital Infrastructure Design and Pilot

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## Executive Summary

### **Background**

The rapid advancement of automated vehicle (AV) technology necessitates a reevaluation of California's roadway infrastructure to ensure seamless integration with emerging transportation systems. As AV deployment progresses, transportation agencies like Caltrans must address both physical and digital infrastructure needs to enhance safety, efficiency, and interoperability. The transition from conventional roadways to AV-friendly corridors requires significant research to determine the most effective strategies for designing and implementing digital infrastructure solutions, such as connected vehicle systems, advanced traffic management, and real-time data-sharing capabilities.

Currently, much of California's transportation infrastructure is designed for human-operated vehicles, lacking the necessary digital elements to support AVs at scale. Without adequate infrastructure modifications, AVs may struggle with roadway inconsistencies, outdated signaling, and limited real-time connectivity. Research into Caltrans' roadway digital infrastructure will provide critical insights into optimizing road markings, signage, and communication networks for AV navigation. Additionally, studying pilot programs will help refine best practices for digital roadway deployment, ensuring that infrastructure investments align with evolving AV technology and regulatory requirements.

The Division of Traffic Operations is seeking information on existing research studies which are relevant or related to "Caltrans Roadway Digital Infrastructure Design and Pilot." This research is essential for developing a strategic roadmap that guides Caltrans in creating AV-ready roadways while considering challenges such as data security, sensor reliability, and interagency coordination. By investigating how digital infrastructure can enhance AV performance, reduce congestion, and improve road safety, the project will play a key role in preparing California's transportation network for the future of automated mobility.

## **Summary of Findings**

### **"Investment and Financing of Roadway Digital Infrastructure for Connected and Automated Driving"**

The study explores optimal investment strategies for vehicular connectivity and roadside sensor deployment under varying traffic conditions. It emphasizes the importance of strategic planning in developing digital infrastructure to support Connected and Automated Vehicles (CAVs). The research identifies investment policies that maximize efficiency, considering different traffic flow scenarios to determine the most effective approach to infrastructure deployment. Additionally, it highlights the need to tailor infrastructure investments based on specific traffic conditions to ensure the best possible outcomes in terms of safety and operational effectiveness.

This study closely aligns with the Caltrans Roadway Digital Infrastructure Design and Pilot (CRDI) project, as both emphasize thoughtful planning and traffic-specific deployment of digital infrastructure. The CRDI initiative similarly considers various use cases, such as traffic operations, work zone management, and multimodal transportation connectivity, which reflect the study's findings on adapting investments to different traffic environments. By integrating high-definition mapping and real-time data layers, the CRDI project aims to enhance safety and efficiency for all road users, particularly CAVs, aligning with the study's emphasis on smart investment in digital infrastructure.

### **"Impacts of Automated Vehicles on Highway Infrastructure"**

This study examines the impact of Automated Vehicles (AVs) on highway infrastructure, aiming to provide infrastructure owner-operators (IOOs) with insights into potential challenges and necessary adaptations as AV deployment progresses. While the report does not delve into operational policies or regulatory recommendations, it highlights that infrastructure changes will be influenced by policy decisions and operational frameworks. By gathering input from AV industry experts, state agencies, and local transportation authorities, the study identifies key infrastructure concerns and research opportunities related to AV implementation.

A major focus of the study is the interaction between AVs and highway infrastructure, which varies based on SAE Levels of Driving Automation and Operational Design Domains (ODDs). ODDs define where and under what conditions AVs can operate, including factors like road type, speed limits, traffic density, and weather conditions. The report emphasizes that AVs are not a uniform technology but instead encompass diverse vehicle types with different automation capabilities, requiring infrastructure adjustments tailored to specific use cases. Additionally, it acknowledges the dynamic nature of ODDs, stressing the need for continuous evaluation and maintenance of infrastructure elements to support AV deployment effectively.

The study also considers current technologies, such as Advanced Driver Assistance Systems (ADAS) (SAE Levels 1 and 2), which are already in use, and future Automated Driving Systems (ADS) (SAE Levels 3 to 5), which are still under development. While ADS technologies are not yet mature enough to determine their full infrastructure requirements, the study underscores the importance of preparing roadways for increasing levels of automation. By analyzing existing AV capabilities and anticipated advancements, this research serves as a foundation for future studies on AV-infrastructure integration.

## **Gaps in Findings**

The study presents certain gaps that should be addressed in future research. While it effectively outlines investment strategies, it does not fully explore the technological challenges and interoperability issues that come with large-scale digital infrastructure deployment. Additionally, there is limited discussion on policy frameworks, data-sharing standards, and cross-agency coordination, all of which are critical for successful statewide implementation.

The study touches on infrastructure adjustments but does not provide concrete evaluation metrics for determining how ready the infrastructure is for AV deployment.

## **Next Steps**

To bridge these gaps, further research should focus on developing a standardized digital infrastructure framework, testing interoperability between multiple systems, and assessing long-term maintenance and funding models. The next steps for the CRDI project should include pilot studies in varied traffic environments, stakeholder engagement to refine implementation strategies, and collaboration with policymakers to establish regulatory standards that ensure a seamless and future-proof digital roadway network.

Caltrans could include frameworks or guidelines for assessing the current state of Caltrans roadways and their readiness for AV integration, including considerations for sensor accuracy, latency, and data security.

## Detailed Findings

### Background

Connected Automated Vehicles (CAVs) rely on sensors to scan and analyze their surroundings, enabling them to make informed and efficient driving decisions. However, these sensors have limitations in spatial range and resolution, making full autonomy challenging. To overcome these limitations, cooperative sensing through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications enhances CAVs' environmental awareness by facilitating data sharing between vehicles and roadside infrastructure. This study examines the optimal investment strategy for deploying vehicular connectivity and roadside sensors under different traffic flow conditions. It also extends the self-financing theorem to sensor-equipped roads, analyzing whether an optimal toll can offset both construction costs and the expenses of equipping roads with sensing technology.

The study's findings reveal that investment priorities should shift based on traffic conditions. When budgets are constrained and traffic flow is low, investing in physical infrastructure improvements is the most effective strategy. However, as traffic volume increases, enhancing connectivity and data-sharing capabilities among CAVs becomes a more valuable investment. Interestingly, under high traffic flow conditions, there may be a shift back to prioritizing stationary roadside sensors depending on system parameters. These insights provide a framework for budget allocation that optimizes CAV performance, contributing to the development of safer and more efficient automated driving systems.

Additionally, the research explores the economic feasibility of financing digital infrastructure through user tolls. It finds that optimal tolling strategies alone are insufficient to cover digital infrastructure construction costs. However, when policymakers account for the safety benefits of sensor-equipped roads, these toll revenues can justify infrastructure investments. Furthermore, the study concludes that if a roadway's flow-capacity ratio exceeds a certain threshold, toll revenues can sufficiently fund the deployment of roadside sensors, making it financially viable to equip existing roads with sensing technology.

## **Related Research and Resources**

**Investment and financing of roadway digital infrastructure for automated driving**, Transportation Research Part B: Methodological, Volume 192, 2025, 103146, ISSN 0191-2615, Amir Ahmadian, Sina Bahrami, Mehdi Nourinejad, Yafeng Yin, <https://doi.org/10.1016/j.trb.2024.103146>.  
(<https://www.sciencedirect.com/science/article/pii/S0191261524002704>)

**Impacts of Automated Vehicles on Highway Infrastructure**, PUBLICATION NO. FHWA-HRT-21-015, MARCH 2021, Deepak Gopalakrishna, Paul Carlson (ORCID 0000-0003-0859-9305), Peter Sweatman, Deepak Raghunathan, Les Brown, Nayel Urena Serulle  
[FHWA-HRT-21-015: Impacts of Automated Vehicles on Highway Infrastructure](#)