2021

PATH Research Roadmap 2021

CALIFORNIA PARTNERS FOR ADVANCED TRANSPORTATION TECHNOLOGY

Introduction

The purpose of this document is to present a near-term roadmap for advancing research in key focus areas that are: (1) within PATH expertise; (2) consistent with the Caltrans 2020-2024 Strategic Plan; and (3) thematically predominant in the recent federal Infrastructure Investment and Jobs Act (IIJA). This research roadmap focuses on new ideas with respect to the changing priorities at both a federal and state level. In addition, it provides a range of sample projects within these new areas.

For projects focusing on connected and automated vehicles (CAV), the reader is directed to consult the Connected and Automated Vehicle Research Roadmap delivered earlier this year in January 2021.

This document identifies actionable research to leverage emerging technologies to fulfill Caltrans' strategic goals. In addition, it provides a snapshot of evolving conversations between PATH researchers and Caltrans stakeholders as of November of 2021.

Background

Transportation today consists of a variety of mostly disconnected solutions. This disconnection manifests itself physically, operationally, or in other ways. For example, traffic management centers do not communicate with those in neighboring jurisdictions. Private mobility solutions rarely communicate with public mobility solutions. Public transportation agencies may not even coordinate operations with each other. The ability for vehicles and infrastructure to communicate is in its infancy.

This lack of connection reduces the efficiency and effectiveness of our transportation system. Challenges exist in the physical infrastructure, the digital infrastructure, and in the balanced coordination of both.

Moving transportation forward involves a myriad of challenges, including: (1) How transportation data needs to be understood, organized, communicated, and shared; (2) how to enable truly integrated planning, asset management, operational strategies, and MaaS (mobility as a service) solutions; and (3) balancing connectivity, privacy, and security issues while ensuring transportation equity and equal access to benefit all areas of society.

This roadmap proposes near-term efforts that begin to address some of these fundamental questions while considering the context of pressing needs such as safety and climate change.

Themes from the Infrastructure Investment and Jobs Act

Transportation is foundational to the access of economic opportunities, social interaction, and well-being. The following themes from the IIJA serve to focus this roadmap.

Cybersecurity

With recent high-profile ransomware attacks such as the one on the Colonial pipeline, there is greater awareness that increased connectivity of our infrastructure carries risks of being hacked. As a result, substantial funds in the IIJA are allocated to protect the National Highway System from cybersecurity threats, and to mitigate risks. This funding includes support for educational resources and support for implementing best practices.

Data

Many data-related themes overlap with safety, operations, and human factors. Research is needed to improve connectivity, integration, and sharing of data. Example applications may enable transportation asset and project plan information to be conveniently packaged to support vehicle-to-infrastructure (V2I) for work zones and digital twins for signage.

There are calls for a new data ecosystem with new tools for analysis, visualization, and sharing of safety data among federal, state, and local agencies. Funding is allocated for data-driven approaches to identify strategies to achieve “Vision-Zero” and for building and deploying systems to reduce driver distraction.

Pedestrians and Bicycles

Vulnerable road users such as pedestrians and bicyclists continue to have an evolving relationship with CAVs and infrastructure. There are calls to establish a research plan including roadway design, safety countermeasures, and other tools to evaluate the effects of transportation improvements on cyclist and pedestrian safety.

PATH has substantial expertise in this area from previous and continuing projects involving “complete streets” and bicycling studies on the San Rafael Bridge. This expertise can be leveraged to develop methodologies to evaluate design improvements that will accommodate all users. Vehicle technologies that improve pedestrian and bicycle safety through detection and automated braking systems are also promising areas for advancement.

Operations

Themes on transportation operations inevitably overlap with data collection and systems integration for better traffic monitoring and performance measurement. Funds in the IIJA are allocated for R&D in real-time tools to integrate sensor-based infrastructure, CAV data, real-time weather, and incident information.

Another set of themes involve dual goals of carbon reduction and congestion relief through a combination of congestion pricing, demand shift, and investments in other multimodal solutions and infrastructure. Included in this thrust is funding to convert stranded dedicated short-range

communications (DSRC) infrastructure to comply with the new cellular vehicle-to-everything (C-V2X) rollout.

New methodologies are required to quantify the effect of increased bicycle and pedestrian facilities on vehicle miles travelled (VMT), and to incorporate those effects into cost-benefits analyses. This kind of holistic assessment is needed to understand how to offset potential VMT increases on one project with reduced VMT through improved bicycle and pedestrian infrastructure on another.

Resiliency

Themes on resiliency involve questions of climate change, wildfires, and evacuations. Funding is allocated in the IIJA to strengthen and protect evacuation routes through investment in technology, communications, and infrastructure. It is increasingly important to consider a holistic risk assessment of evacuation routes due to vegetation, road network topology, and other factors.

Revenue Collection

With momentum growing towards alternative fuel vehicles, the existing gas tax for transportation funding will become inadequate. Funding is allocated in the IIJA to test feasibility of a road usage fee, and alternatives. Pilot projects are envisioned that protect privacy, are easily enforced, and are scalable to the nation.

Caltrans Strategic Goals

This roadmap assembles a portfolio of research activities in the matrix of projects, below. Taken together the projects in this portfolio address each of the strategic goals enumerated in the 2020-2024 Strategic Plan:

- Safety first
    - Included are projects specifically focused on safety, or using data systems to analyze, understand, or improve safety and operations.
- Cultivate excellence
    - This research portfolio opens new possibilities to leverage the latest technologies. Cutting-edge solutions adopted in California can become a model of organizational excellence and be copied across the United States and around the world.
- Enhance and connect the multimodal transportation network

    - Projects span multiple modes, identify gaps in multimodal networks, and include studies to improve the connection between modes. Operational strategies are investigated including demand management and dynamic tolling.

- Strengthen stewardship and drive efficiency
    - Projects to improve Caltrans' digital infrastructure focus on modernization, standards, and best practices for cybersecurity and data security. Included are projects to leverage advances in cloud computing, artificial intelligence, and machine learning to enable new possibilities in operational strategies and efficiencies.

- Lead climate action
    - In light of recent events involving recent wildfires and evacuations, there is renewed focus in this portfolio on disaster preparedness, evacuation planning, and resilience to climate change. Projects on VMT monitoring, performance measurement, and analysis are proposed for truck movements and freight, for rural project evaluation, and for evaluation of managed lanes in urban environments.

- Advance equity and livability in all communities
    - Included are projects that address equity, vulnerable populations, and disadvantaged travelers.

Focus Areas

The matrix of projects, below, are mostly new ideas, but also contain some recently proposed and existing projects. They are organized according to the following key focus areas:

- Transportation system operations and simulation (SysOps/Sim)
- Data integration, system interoperability, Artificial Intelligence (AI), and data analytics (Data/Systems)
- Multimodal, Transit, and Freight (MMod/Transit/Freight)

Most of the projects have additional linkages to other areas of active interest and research, including:

- Environmental protection, sustainability, and climate change
- Computing and cybersecurity
- Equity and transportation justice
- Human factors
- Connected and Automated Vehicles, and Active Safety

Matrix of Project Descriptions

Focus Area	Key Words	Project Title and Summary
Data/ Systems	Work Zone, Safety, Crash Avoidance, Data collection	**Improving Safety and Efficiency of Work Zones in California:** Develop and demonstrate a Smart Work Zone application that will improve how data about work zones is collected and disseminated in California. Leverage and integrate key technologies, industry standards, and systems at UC Berkeley (UCB), the Federal Highway Administration (FHWA) and Crash Avoidance Metrics Partners (CAMP). If widely deployed, the application will improve the safety and efficiency of work zones on California roadways.
Data/ Systems	Infrastructure maintenance, asset management, public-private partnership, feasibility analysis	**Using AV testing data for proactive identification of roadway infrastructure maintenance needs**: Feasibility analysis for public-private partnership to (1) leverage existing data collected by autonomous vehicle (AV) companies; (2) use the AV testing data for detection of road infrastructure conditions, such as worn-out lane marking, and potholes; and (3) facilitate proactive roadway facility assessment for better road infrastructure maintenance.
Data/ Systems	TMDD Modernization, C2C communications, CATMS, standards, computation	**California C2C Specification for CATMS**: Follow-up on the recommendations regarding customer-to-customer (C2C) communications developed in the Traffic Management Data Dictionary (TMDD) Modernization project. Generate a C2C specification for California to be implemented within the Correspondence and Task Management System (CATMS) program and within the District 3 CATMS proof-of-concept effort. Standardization of communications will enable new flexibilities and reduce costs of future procurements and integration efforts.
Data/ Systems	Cybersecurity, resilience, disaster preparedness, computation	**Improving Infrastructure Resilience for Disaster Preparedness and Cyber Threats**: Analyze the current Caltrans information systems environment and determine cost-effective alternatives and upgrades that would both increase its security and improve its resilience to failure caused by natural disasters such as wildfires, earthquakes, or flood, or by cyberattacks such as social engineering attacks, ransomware, state-actors, and others.

Data/ Systems	Cloud computing, standards, data sharing, data integration, data security, computation, security	**California Transportation Research Cloud**: Develop a California Transportation Research Cloud with the following objectives: 1. Create a standard for Caltrans cloud transition for information systems 2. Develop a shared transportation research data set for Caltrans research and research partners 3. Create a cloud-based system for storage and analysis of data from programs related to CAV and other upcoming transportation technologies 4. Partner with Caltrans to transition knowledge related to cloud-based systems operation and security of cloud operations
Data/ Systems	VMT analysis, rural trips, demand data, equity	**Strategic VMT analysis**: Develop a data-fusion methodology for creating a high-resolution zone-less travel demand data set. Using traditional public data sources, such as from the US Census, as well as emerging third-party microdata sources, the data can be fused to synthesize a disaggregated data set (or aggregated for privacy concerns) which contains detailed socio-demographic and trip origin-destination patterns using cartesian coordinates rather than zones. Such a data set could provide a range of potential applications. For example, identifying areas of VMT reduction and strategic investment to address equity in travel options, but also feed into larger travel demand models. In rural areas, this approach avoids obscuring short but important trips that make up approximately 75% of trips that could provide crucial VMT reduction.
Data/ Systems	Managed lanes, HOV degradation, data analytics	**Leveraging imperfect data for HOV Degradation Analysis**: Generate guidelines to determine the admissibility of data to be used for high-occupancy vehicle (HOV) degradation analysis, and to create algorithms to use indirect evidence to estimate HOV degradation from imperfect data. Consider the viability of using third-party speed data to detect possible erroneous sensors.
Data/ Systems	Data quality, performance measures, artificial intelligence, machine learning	**Data Integrity of Managed Facilities:** Use artificial intelligence and machine learning to improve the accuracy of performance measures. This project is a follow-on of the successfully completed Task 3710. However, it will extend the methods to other managed-lane facilities across California. The main goal is to develop automated means to identify configuration errors on managed facilities such as Express

		and HOV lanes, especially those with variations in rules/prices for time-of-day operations.
Data/ Systems	Data quality, performance measures, third-party data, big data, bias, equity	**Evaluating The Accuracy of third-Party Volume Data**: There is a growing interest in using 3rd party probe-based data to conduct traffic analysis studies. While these data sources can provide valuable additional information about observed speeds and travel times, some uncertainty remains about the accuracy of the estimated volumes. This is due to the fact that the collected data is based on a sample, not a full observation of traffic. Biases may exist towards capturing travelers who are more prone to use connected devices, as well as travelers with higher disposable income. Research would help Caltrans determine the usefulness of reported volumes and define their potential use in project assessments by assessing differences between estimated volumes and actual counts for various locations along key freeways and highways.
MMod/ Transit/ Freight	Disadvantaged travelers, equity, shared AVs, mode choice	**Public Acceptance of Shared AVs for disadvantaged travelers**: Understand the transportation needs and challenges for people with disabilities in California, their future adoption of SAVs, and the potential change of their transportation mode choices as SAVs become available.
MMod/ Transit/ Freight	Safety of vulnerable road users	**Automated vehicle (AV) communication with pedestrians and vulnerable road users (VRU)** is a critical research question for AV's acceptance by the general public. This research topic is not only a question of design. Rather, it is a complicated research question associated with other aspects of AV deployment, including AV’s safe operation domains, infrastructure upgrade for segregating VRUs from AVs, traffic regulation for mixed-mode driving, as well as AV standardization and public education.
MMod/ Transit/ Freight	Transit, connection, data sharing, integrated mobility	**Connection Protection Pilot Study**: Connection Protection (CP) is a dynamic operational application for transit, aiming to increase the success of transit transfer by connecting agencies, bus operators and riders using transit real time data. PATH supports AMG in exploring CP opportunities in Solano County and will develop and test the data engine to enable the application.
MMod/ Transit/	Freight, truck movement, third-	**Leveraging Emerging Third-Party Data to Improve Truck Monitoring in Urban Areas**: Assess the reliability of

Freight	party data, operations	StreetLight or other probe-based truck data sources in correctly characterizing truck movements in urban environments. This project would be a follow-up of an existing SB1 project looking at the ability to use StreetLight data to assess truck movements within Caltrans District 1. In urban areas, Caltrans currently collects truck volumes by class from a very limited number of locations. This results in difficulty to assess truck movements, particularly in complex urban networks such as Los Angeles.
MMod/ Transit/ Freight	Multimodal, connectivity, mobility measures, environment	**Multimodal network connectivity measures**: Create measures to identify critical gaps in multi-modal networks and highlight possible sources of underperforming links. This project builds on previous efforts to develop a bicycle network connectivity measure using elements of graph theory. This concept would be expanded to encompass multimodal connections such as park-and-ride, bike-and-ride, and others.
MMod/ Transit/ Freight	Data, trip planning, equity, disadvantaged riders	**ITS4US Complete Trip Program:** This California Association for Coordinated Transportation (CALACT) project aims to address the need for riders who use demand-responsive services such as rural riders, and riders with disabilities, to have equal access to the real-time trip planning technologies already available for fixed-route transit. PATH will contribute to the tasks of technical advice, data quality review, and performance evaluation.
SysOps/ Sim	Wildfire, evacuation, risk assessment, operations, local agency coordination	**Wildfire evacuation meta-analysis**: Perform meta-analysis of wildfire evacuation case-studies to identify emerging needs for holistic state-wide risk assessment of evacuation routes due to vegetation, road network topology and other factors. Explore benefits of smart infrastructure technology to improve communication, coordination, and execution of an evacuation plan.
SysOps/ Sim	Dynamic tolls, equity, demand elasticity, operations, managed lanes	**Market strategies to incentivize peak-congestion reduction:** Feasibility analysis to augment existing electronic fare collection systems (e.g., dynamic tolls) in a "futures" market to enable travelers to pre-pay tolls at a dynamic discount in exchange for arriving at an agreed upon future time. Such a system is expected to enhance the price elasticity of demand of dynamic tolls, to have a greater impact on demand for each unit change in price compared to conventional on-the-spot dynamic pricing. As an opt-in system it averts primary equity concerns for casual travelers but

		provides a relief path for regular commuters to stabilize their regular commuting tolls. With further partnership, this research could easily progress from theory to practice in a pilot project for any of Caltrans' growing number of dynamic tolling facilities (e.g., a high occupancy toll [HOT] lane), or for transit systems.
SysOps/ Sim	Simulation, CAV application	**A hardware-in-the-loop microsimulation platform for the testing of CV/CAV applications:** Create a hardware-in-the-loop microsimulation framework to test existing functions in the Multimodal Intelligent Traffic Signal System (MMITSS) system. As a research outcome from the Caltrans project (Task 3712: System impact of connected and automated vehicles: An application to the I-210 Connected Corridors pilot), a microsimulation platform in Aimsun has already been developed to mimic the “real” mixed traffic environment with CVs/AVs/CAVs. It will be years until there are a significant amount of CVs/AVs/CAVs running on surface streets, so building a “real” mixed traffic environment becomes crucial for the testing of CV/CAV applications. With the External Agent Interface (EAI) module provided by Aimsun, we will be able to further extend the developed microsimulation platform to incorporate actual traffic controllers/systems in the field to test various CV/CAV applications. One candidate test site would be the California Connected Vehicle testbed, in which we can establish the connection with the MMITSS system via the EAI module.
SysOps/ Sim	Artificial intelligence, deep learning, signal coordination, operations	**Optimization of signal coordination with deep reinforcement learning (RL)**: Signal coordination along major arterial streets is often disrupted by time-varying traffic demand and vehicle routes. Our previous studies have demonstrated the benefits of applying Deep RL to optimize signal coordination at five intersections along Huntington Dr. in the City of Arcadia. In this project, we aim to develop a hardware-in-the-loop approach to incorporate actual traffic controllers in the field and evaluate the performance of the proposed optimization framework with Deep RL. We will first use microsimulation in Aimsun to evaluate the robustness of the proposed optimization framework at other coordinated arterial streets, e.g., those in the City of Pasadena in the I-210 Connected Corridors Pilot. Once the proposed optimization framework is fine-tuned, we will use the External Agent Interface (EAI) module in Aimsun to incorporate field controllers in the loop. One potential candidate test site would

		be the California Connected Vehicle Testbed, in which the MMITSS system already has built-in functions to change offsets in the field controllers.
SysOps/ Sim	ICM, incident management, navigation apps, simulation	**Evaluating the impact of navigation apps on traffic incident management**: Evaluate potential adverse impacts of navigation apps on traffic incident management. Develop a collaborative framework to include navigation apps in the development of response plans. Navigation apps are so popular that their impacts on traffic cannot be ignored. App-based routing recommendations may undermine response plans developed and implemented by Caltrans. Simulations of incidents occurring at different locations along the I-210 freeway will be performed and impacts of navigation apps on the recommended response plans with and without collaboration will be evaluated.
SysOps/ Sim	Simulation, RSU, CAV applications	**Guideline on RSU placement to facilitate the deployment of CAV strategies:** This project leverages the microsimulation platform in Aimsun to develop guidelines on RSU placement to facilitate the deployment of CAV strategies. A microsimulation platform in Aimsun has been developed to mimic the “real” mixed traffic environment with CAVs, both at the vehicle control level (e.g., Adaptive Cruise Control [ACC] and Cooperative Adaptive Cruise Control [CACC]), and the communications level (e.g., V2I, infrastructure-to-vehicle [I2V], and vehicle-to-vehicle [V2V] communications). The locations of RSUs play an important role in the performance of certain CAV strategies, for example, freeway speed harmonization with CAVs. Choosing the right locations for RSUs is essential since the application performance is closely related to road geometry, traffic demand, and vehicle routes. Therefore, it is crucial to understand where to put RSUs so as to achieve desired traffic performance while staying within budget. PATH will work closely with Caltrans engineers to determine a set of candidate CAV strategies. Next, we will develop APIs to enable these strategies in the microsimulation platform in Aimsun and use the I-210 Connected Corridors Pilot model to determine the benefits of different approaches on RSU placement. Practical guidelines will be established based on the results from various simulation scenarios in the I-210 model.

SysOps/ Sim	Performance measurement, signal phasing, data and systems, operations	**Development of Automated Traffic Signal Performance Measures (ATSPMs) using signal phasing and NoTraffic Data**: In the California Connected Vehicle testbed, NoTraffic sensors are installed at multiple intersections (e.g., El Camino Real@Embarcadero Rd) to detect vehicle and pedestrian movements at a high resolution. Unlike existing ATSPMs systems which require upgrades like installation of new detectors and changing traffic measurements from cycle-based to event-based, we aim to construct ATSPMs using the vehicle/pedestrian trajectory data from NoTraffic sensors and the signal phasing data from conventional traffic controllers. In particular, we will conduct the following tasks: 1) evaluate what performance metrics (e.g., Purdue coordination diagram, Purdue split failure, split monitor, etc.) we can compute based on the available data; 2) develop algorithms to construct these performance metrics; and 3) develop an interactive tool to visualize signal performance at the intersections equipped with NoTraffic sensors.
SysOps/ Sim	VMT analysis, rural trips, environment	**Investigating Ability to Assess VMT Impacts of Rural Capacity-Enhancing Projects**: Determine whether typical capacity-enhancing projects conducted on rural elements of the state highway system generally cause measurable increases in VMT. Given the expected limited demand data available for assessing each project, the goal is not to develop specific VMT elasticity factors associated with each project type but rather to determine whether specific types of projects executed in rural areas are likely to lead to significant increases in area VMT. While it is possible that available data may not allow a clear determination of trends in VMT impacts for all types of projects, it is expected that the collected information will at a minimum be used to inform future research on the topic.
SysOps/ Sim	VMT analysis, managed lanes, environment	**VMT Impacts of HOV lane conversions**: There is currently a lack of information about the potential effects of converting HOV 2+ lanes into 3+ or 4+ lanes. This project could try to identify whether such changes have been implemented in the past and if evaluations on resulting impacts on VMT have been conducted. Alternatively, a simulation study to assess how the VMT might change following a change based on various assumptions of shifts in vehicle occupancy. This information could be used to identify target changes under which a project might be viable in terms of VMT reductions.