CALIFORNIA PATH TRIENNIAL REPORT

2020-2023

University of California, Berkeley
Institute of Transportation Studies

California Partners for Advanced Transportation Technology
www.path.berkeley.edu

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Message from the Directors – Scott Moura and James Fishelson

PATH was founded in 1986 in close partnership with Caltrans Division of Research, Innovation and System Information (DRISI). Today, PATH is a global leader in advanced transportation technology research. PATH's unique specialty is advancing transportation technologies from academic research to deployment. These technologies improve transportation for all, making it cleaner, safer, more sustainable, more equitable, and more efficient. This mission has never wavered, and we fully intend to maintain it for the next 38 years. With that being said, the transportation technology space has and will continue to change rapidly, and PATH will continue to play a leadership role in these changes. For example, PATH has been leading automated and connected Vehicle research since the 1990s, but the industries are massively different now than they were even three years ago. New opportunities crop up with regularity, from digital infrastructure to unmanned aerial vehicles, to generative AI. PATH will continue to support Caltrans by identifying and advancing these technologies toward deployment.

As part of this process of constant adaptation and flexibility, PATH welcomed new leadership, wishing a fond farewell to Tom West and Trevor Darrell. They were replaced by the new Executive Director James Fishelson, who started in May 2022, and the new Faculty Director Scott Moura, who started in January 2022. Dr. Fishelson came to PATH from Ford Motor Company, where he led a Mobility Research Group. Prof. Moura is an Associate Professor in Civil and Environmental Engineering, where he directs the Energy, Controls, and Applications Lab (eCAL). Both are committed to continuing and expanding on PATH's long history of practical research support to Caltrans, including but not limited to: leveraging more federal funding, bringing in more corporate partners, providing more nimble and short-term deliverables to meet pressing Caltrans needs, ensuring more knowledge transfer to both headquarters and the individual districts, and staying abreast of the most important and impactful new technology areas.

The new Future Mobility Research Center (FMRC) contract, which replaced the old PATH Management Contract (PMC) as of January 12, 2024, will help support the above goals, with the added benefit of substantially trimming administrative costs and creating a much more deliverable-focused contract. However, PATH started implementing its more ambitious goals well before this new contract. For example, we strove to go above and beyond the core PMC deliverables described in this contract, performing Caltrans support work such as creating a CAV application roadmap at the request of Traffic Operations in Headquarters and holding multiple "Train the Trainers" sessions, providing manuals, code, and other guidance to help ensure that Caltrans engineers can support advanced technologies and develop their own CAV lab, e.g., with the Multi-modal Intelligent Transportation Traffic Signal (MMITTS) system.

We also expanded our external outreach efforts, such exploring partnership opportunities between PATH, Caltrans, and other groups in California and beyond, such as: Verizon, AT&T, Audi/VW, Cummings, Waymo, Cruise, UMTRI, KATECH (a Korean institute that blends government, industry, and academia),

University of New Mexico, Microsoft (for AI), Hyundai, UCLA, WSP, Qualcomm, Alameda County Transit, and much more. Correspondingly, we have increased our external funding efforts in partnership with Caltrans, such as with a $7.5 M proposal to FHWA for a “Center of Excellence on New Mobility and Automated Vehicles” (ranked #2 out of approximately 28 proposals, but unfortunately they only granted 1). Another example is an $18 M proposal to the USDOT for “V2X: Saving Lives with Connectivity” that is still pending, and has both Traffic Operations HQ and District 4 as major funded members. This project would include installing CV Infrastructure along San Pablo Avenue and I-80. We look forward to expanding these efforts and bringing in more private partners and funding, to leverage existing Caltrans support and advance technologies from research to deployment..

Additionally, PATH has redoubled its efforts to encourage more collaboration with other professors and centers on campus. This ensures that Caltrans has access to all that UC Berkeley has to offer. This includes the PATH-affiliated Berkeley Deep Drive program, which focuses on artificial intelligence and deep reinforcement learning for vehicle automation and overall improvement of the transportation system. Other partnerships within ITS Berkeley include the Safe Transportation Research and Education Center (SafeTREC) and the Transportation Sustainability Research Center (TSRC). We have also worked with Professors Mark Hansen and Raja Sengupta on UAVs, partnered with the Haas School of Business to host the “Hass Mobility Summit,” and much more. Similarly, we have continued our work with other government stakeholders and funders with an eye toward supporting Caltrans efforts. This includes a recently awarded SMART grant to create a data platform to support multimodal accessible transportation, an on-going multi-million dollar DOE project to support cooperative adaptive cruise control and platooning, and other similarly-sized DOE projects focused on connected vehicles and energy efficiency for automated electric vehicles.

We are incredibly excited for the next few years. California has been and will continue to be a global leader in transportation technologies, developing and deploying advanced technologies in ways that make life better for everyone. With the advent of automation, connectivity, electrification, AI, and much more, the field of transportation is at the cusp of a revolution the likes of which we haven’t seen since the adoption of the automobile itself. We are honored to work with Caltrans at such an exciting time and know that together we will drive California to new frontiers in transportation leadership.

Message from Caltrans - Dara Wheeler

I am honored to provide a message from Caltrans to reflect upon the joint activities of California Partners for Advanced Transportation Technology (PATH) and Caltrans over the last two years and to talk briefly about the future of transportation in California.

As the Chief of the Division of Research, Innovation and System Information (DRISI), my colleagues and I take great pride in promoting and implementing innovation to provide a safe, sustainable, equitable, integrated, and efficient transportation system for all travelers in California. DRISI works with partners like PATH to discover, develop, and deliver technological solutions that solve some of California's most critical transportation issues. This work involves guiding each project through various stages of development, including advanced research, prototype development, prototype and field testing, and deployment in order to quickly achieve the benefits of a proposed innovation.

For nearly a quarter century, Caltrans and PATH have honed their relationship to ensure the efficient delivery of significant and meaningful research and to rapidly adjust to changing statewide priorities. Specifically, PATH provides the knowledge and expertise to assist Caltrans innovative projects involving autonomous vehicles, traffic management systems, and connected vehicles, just to name a few. I deeply appreciate the level of partnership interactions between our organizations and the responsiveness of both PATH and DRISI to each other in order to ensure the most efficient working relationship. I greatly value the partnership that DRISI and PATH have developed over the years and am committed to working together to help shape the future of California's transportation network, CAV technology as well as changing statewide priorities.

Another related example is the ongoing effort to upgrade and support the nation's first Connected Vehicle (CV) test facility called the California Connected Vehicle Testbed. This unique facility is located in the heart of the Silicon Valley and provides the opportunity for industry and academia to test new, breakthrough innovations that hold promise to greatly improve traveler safety and efficiency. These include those that walk, ride bikes, take transit, or drive vehicles.

PATH has always been at the forefront of improved multi-modalism, and this recent period is no exception. PATH has thoughtfully worked with many of the Bay Area transit agencies to understand how best to encourage mode-shift by ensuring reliable and safe transit service. No project better illustrates this than the cooperative work of Tri-Delta Transit and PATH in the development of a sixty-bus demonstration that helped transit users protect their connection to adjoining transit services, in this instance between BART and first/last mile bus service.

There are of course too many projects to mention here but let me sum up by saying that I am quite proud of the PATH and DRISI affiliation, as well as the partnering efforts that carefully assess and select the research that will make a difference in California and is capable of rapid field implementation. For with this final step, we ensure that we will make progress in improving the safety and efficiency of California's transportation system, while at the same time providing more choices to California travelers.

Historical Perspective

Since 1986, the California Partners for Advanced Transportation Technology (PATH) Program at UC Berkeley has paved the way in transforming the landscape of transportation technology, focusing on the development of Intelligent Transportation Systems (ITS) and Connected and Automated Vehicles (CAVs) both inside and outside the state of California. Since its inception, PATH has endeavored to develop and implement cutting-edge technologies that offer significant improvements to the operation of the transportation system. We collaborate with industry partners, government agencies, and academic institutions to address transportation challenges, with a strong focus on advancing sustainable, safe, and efficient mobility solutions for the future. In 2011, the current incarnation of PATH was established through the merging of two University of California (UC) Berkeley programs, the California Partners for Advanced Transit and Highways (PATH) and the California Center for Innovative Transportation (CCIT). PATH is managed by the Institute of Transportation Studies at the University of California at Berkeley.

PATH's comprehensive and expansive research portfolio includes projects on connected and automated vehicles (CAVs), equity, safety, smart mobility, traffic management, zero-emissions mobility, smart cities, transportation connection, and transportation systems optimizations. Many projects include demonstrations and proof-of-concept experiments. Several large-scale programs such as the Innovative Mobility Research (IMR) Program, which helped develop and demonstrate new technologies and approaches to transportation management to improve safety and efficiency, reduce congestion, and enhance mobility for all users, developed out of the PATH Program. We have an extensive, prolific history of field testing and running demonstrations of connected transportation systems on public roads and highways in California and other parts of the United States. This includes the recent Truck Platooning project spearheaded by Dr. Xiao-Yun Lu in partnership with Caltrans and the Federal Highway Administration (FHWA). The NEXTCAR project led by Prof. Scott Moura and Prof. Francesco Borrelli is another example, which utilizes infrastructure-to-vehicle communication to reduce vehicle energy consumption by 30%. Our researchers have helped operate testbeds such as the California Connected Testbed in 2005, and have aided in launching successful research facilities such as Berkeley Deep Drive (BDD) in 2016, which is still operating under PATH.

The Berkeley Deep Drive Consortium was spun out of PATH to provide innovation and intellectual leadership in robotics, artificial intelligence, and computer vision for automotive applications. BDD collaborates with private industry sponsors and brings together faculty, researchers, and students from various departments, including the Electrical Engineering and Computer Science (EECS) Department, Center for Information Technology Research in the Interest of Society (CITRIS), Berkeley Artificial Intelligence Research (BAIR) Lab, California PATH, and the Institute of Transportation Studies. Under the direction of Professor Trevor Darrell, Professor Kurt Keutzer, Dr. Ching-Yao Chan, and Dr. Wei Zhan, BDD integrates cutting-edge technologies in computer vision and deep learning and applies them to autonomous vehicles and robotics. Significant progress has been made in computer vision and robotics, but many of these developments have yet to reach their full potential. BDD seeks to accelerate the development and implementation of these practical technologies for the automotive industry. Work includes fundamental research and implementation in real-world scenarios and focuses on several research themes:

- Machine learning and AI methodologies
- Computer vision and image processing
- Low power and embedded deep learning algorithms

- Extensive and annotated database of real-world driving
- Object detection, tracking, prediction, and scene perception
- Classical and machine learning-based control of dynamic systems
- Robotics and Autonomous Driving applications

Looking Toward the Future

Over the past 37 years, PATH pioneers have significantly contributed to the development of advanced transportation systems. Demonstrations in platooning technology, improving adaptive traffic control systems, vehicle electrification, establishing a Connected Corridors Program, and developing CV, CAV, and AV technology are just a sampling of our accomplishments. PATH seeks to create and actualize a massively improved transportation system for all by combining research and development of advanced transportation technologies with a focus on practical deployment. We are uniquely positioned to build communities between academia, government, and industry. Our organizational structure, San Francisco Bay Area location, and network of partners and stakeholders allow for large and advanced collaborative projects. PATH's strength comes from access to the world's most brilliant innovators at UC Berkeley, considerable historical knowledge, technical expertise, and the motivation to adjust and adapt as technology expands. An entire generation of researchers has been influenced by the research and approaches established by PATH. Our Priority Thrust Areas align with and advance Caltrans' Strategic Goals. Our technical experience and team of thought leaders provide Caltrans with practical, dependable support. As the years have brought new challenges and technological advances, our core competencies have also shifted and evolved. As a resilient and motivated Caltrans partner, we are committed to developing and advancing innovative solutions to address California's unique transportation challenges that are efficient, green, safe, accessible, equitable, and desirable.

Caltrans Mission and Goals

Caltrans is responsible for providing and maintaining a safe, reliable transportation system. It manages the state's more than 50,000 miles of highways, freeways, and bridges; provides intercity rail services; and maintains California's mass transit systems and active transportation infrastructure. The agency has published several documents that have helped shape the transportation landscape, including the Caltrans Strategic Plan and the California Transportation Plan. These documents outline their goals for the future of transportation in California, which closely align with PATH's current mission statement and goals, addressed later in this document.

2020-2024 Caltrans Strategic Plan (CSP)

The Caltrans Strategic Plan outlines six goals and recommends strategies and potential research projects that could be implemented to achieve success in the areas of Safety First, Equity and Livability, Climate Action, Multimodal Transportation Network, Stewardship and Efficiency, and Cultivating Excellence.

- Safety First: Caltrans is committed to the goal of safety first by reducing the number of fatalities and serious injuries on California's roads and highways through initiatives such as the California Strategic Highway Safety Plan and the Zero Traffic Fatalities Task Force.
- Advance Equity and Livability: Caltrans aims to improve the efficiency and reliability of California's transportation system by reducing congestion, enhancing public transit options, and implementing intelligent transportation systems to manage traffic flow. Caltrans is committed to ensuring that all Californians, regardless of their income or background, have access to safe and efficient transportation options. Included are projects that address equity, vulnerable populations, and disadvantaged travelers.
- Climate Action: Caltrans is a leader in climate action and is working to reduce the environmental impact of transportation in California by promoting alternative modes of transportation, such as biking and walking, while investing in sustainable transportation technologies, such as electric vehicles. Projects on vehicle miles traveled (VMT) monitoring, performance measurement, and analysis are proposed for truck movements and freight, rural project evaluation, and evaluation of managed lanes in urban environments.
- Enhancing the Multimodal Network: The Goal of Enhancing and Connecting the Multimodal Network refers to projects that span multiple modes, identify gaps in multimodal networks, and include studies to improve the connection between modes.
- Strengthen Stewardship and Efficiency: Caltrans' goal to strengthen stewardship and drive efficiency encourages projects that improve Caltrans' digital infrastructure's 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 that will enable new possibilities in operational strategies and efficiencies.
- Cultivating Excellence: Caltrans is committed to cultivating excellence, ensuring collaboration with research agencies and other partners who leverage the latest technologies and cutting-edge solutions.

California Transportation Plan (CTP) 2050

Caltrans develops and implements the state's transportation plan, which is updated periodically to reflect current priorities and goals. The most recent iteration of the California Transportation Plan (CTP) was published in December 2022 and provides a vision for the state's transportation system through

2050. It is a roadmap for making effective, equitable, and transparent transportation decisions for California's almost 40 million residents and their communities, and it addresses the varied transportation needs of urban, suburban, rural, and Tribal communities. The plan promotes sustainable transportation options, invests in infrastructure, and provides connections to jobs, housing, services, and recreation. It also seeks to improve the safety, accessibility, and equity of the transportation system, playing a vital role in California's economic opportunities, cost of living, environmental quality, health, and overall quality of life.

Caltrans and PATH

Caltrans and PATH have common goals and visions for the future. As partners, we have collaborated for decades on advancing automotive technology and solving California's transportation challenges. Caltrans' Strategic Goals of improving safety, cultivating excellence, enhancing the multimodal network, improving stewardship and efficiency, promoting climate action, and increasing equity and livability are also integral to the PATH mission statement. Caltrans provides significant funding for PATH research, and in return, PATH's role is to help guide Caltrans in making strategic technology-related investment decisions that deliver state goals and facilitate training for new, data-driven approaches focused on collaborative community and partner engagement. Achieving our shared goals will require the strategic deployment of existing and emerging technologies in a way that encourages a reduction in dependence on single-occupant vehicles and increases access to destinations and job opportunities.

California's Transportation Priorities

The California transportation system features a vast system of freeways, roads, and public transit options such as buses, trains, and other modes of transportation. Unfortunately, it contributes significantly to greenhouse gas emissions (40% of total) and is undergoing numerous initiatives to reduce negative environmental impacts, including state investments in clean energy and zero-emission vehicles. Additionally, California's transportation infrastructure needs improvements that can support emerging transportation technologies and meet the demands of California's growing population and changing mobility patterns. California policymakers have addressed our state's challenges by investing in infrastructure and sustainable transportation, improving public transit and bike lanes, and implementing technological advancements that improve efficiency, sustainability, and safety. Several large-scale bills, plans, and pledges have resulted in forward action. The Road Repair and Accountability Act of 2017 (Senate Bill 1), the Climate Action Plan for Transportation Infrastructure (CAPTI), and the California Climate Commitment Executive Order are all state-funded legislation that addresses these concerns. This report highlights themes and specific goals from these policies and covers PATH's body of work from June 2020-2023, as well as future trends in transportation technology.

Road and Repair and Accountability Act (SB1)

Senate Bill 1 (SB1) provides funding for transportation infrastructure projects, including local streets and roads, trade corridor enhancement, and solutions for congested corridors and is the first significant increase in state transportation funding in more than two decades.

Climate Action Plan for Transportation Infrastructure (CAPTI) (2021)

The Climate Action Plan for Transportation Infrastructure (CAPTI) tackles the issue of how existing state transportation infrastructure investments should be leveraged to meet state goals. CAPTI has identified ten guiding principles and eight strategies encompassing 31 key actions. These actions pertain to both

current and future changes in state transportation planning, project scoping, programming, and mitigation activities. Since its implementation in July 2021, CAPTI has completed 12 of these actions, with 18 currently underway and four in early progress. CAPTI funding will work to reduce Californians' dependence on driving, increase multimodal options for all communities, advance climate protection, promote sustainable transportation solutions, build toward an integrated, statewide rail and transit network, and invest in networks of safe and accessible bicycle and pedestrian infrastructure as well as light, medium, and heavy-duty zero-emission vehicles (ZEVs).

Federal Infrastructure Investment and Jobs Act (IIJA) of 2021

Following the implementation of CAPTI, significant progress has been made in transportation funding at both the federal and state levels. In many cases, these notable increases in funding align closely with the principles outlined in CAPTI. On November 15, 2021, the federal government enacted the Infrastructure Investment and Jobs Act of 2021 (IIJA), marking a historic milestone for the United States. California benefits from this legislation with an allocation of over $5.5 billion in funding. These funds will be directed towards a range of essential investments, including climate action initiatives and equitable transportation solutions, as well as advancements in rail and transit systems such as:

- Enhancing active transportation projects to create safer and pedestrian-friendly streets.
- Expanding the statewide network of fast-charging stations for public electric vehicles (EVs).
- Strengthening the resilience of transportation infrastructure to withstand the impacts of extreme weather events and climate change.
- Providing support for transit services, including bus and rail systems and multimodal facilities.
- Restoring connectivity among communities that have been historically divided by transportation infrastructure. [1]

These initiatives aim to promote sustainable and accessible transportation options, improve climate resilience, and foster stronger community connections throughout California.

California Climate Commitment

Cars, trucks, and other vehicles account for 40% of California's emissions. To address this statistic, California has adopted a goal to have five million zero-emission vehicles on its roads by 2030. Over the next six years, over $37 billion has been allocated to address climate protection in California. In 2021-2022, California made significant progress towards achieving zero emissions mobility. In September 2021, Governor Gavin Newsom signed an executive order to phase out the sale of new gas-powered cars and trucks by 2035. This initiative is part of California's plan to achieve carbon neutrality by 2045. Governor Newsom also proposed $6.1 billion in new funds to promote EVs, including $256 million in clean car rebates and other programs for low-income families, $900 million to build electric vehicle chargers in low-income neighborhoods, and $419 million for "community-based transportation equity projects. "[2]

[1] H. R. 3684 - 117th Congress (2021-2022): Infrastructure Investment and Jobs Act | Congress. gov | Library of Congress
[2] California plans to spend $37 billion fighting climate change - Los Angeles Times (latimes. com)

Figure Source: California Air Resources Board; 2023

Figure 1. California's Climate Plan

The state's climate plan would help create four million new jobs, cut GHG emissions by 85%, and decrease gas consumption by 94%. This updated plan sets new targets for renewable energy, clean buildings, carbon removal, and clean fuels in the transportation sector. [3] Unsurprisingly, 2020 had the steepest recorded drop in pollution in California history -- likely due to pandemic lockdowns and an increase in remote work. Figure 2, generated by the California Air Resources Board (CARB), shows the annual statewide emissions from 2000-2020.

[3] California Releases World's First Plan to Achieve Net Zero Carbon Pollution

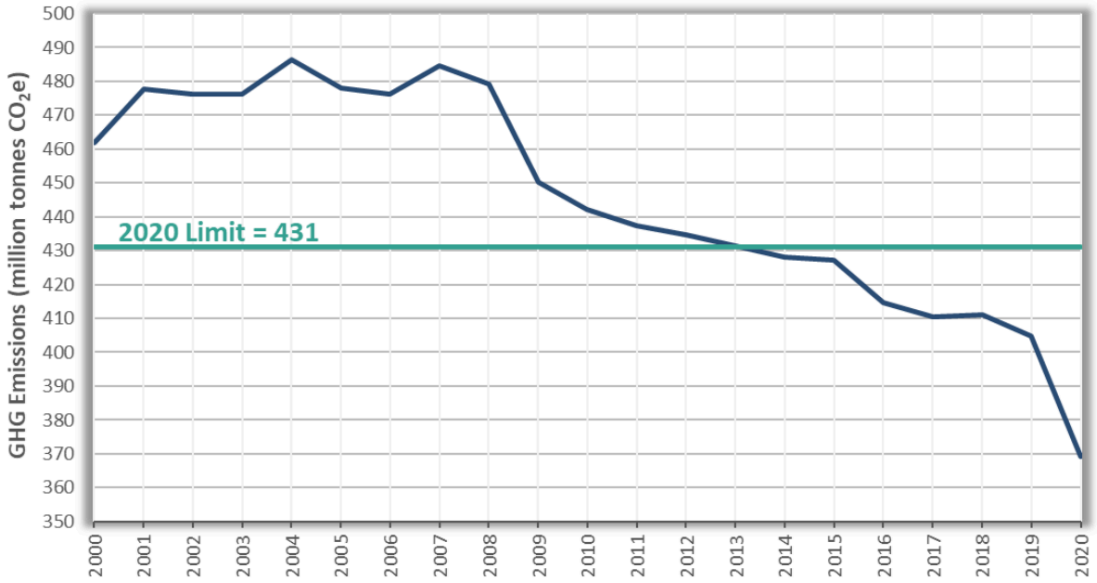


Figure Source: California Air Resources Board; 2023

Figure 2. Annual Statewide Emissions from 2000-2020.

The Future of Mobility in California

The past several years have brought a noticeable shift in the transportation technology landscape. Most notably, the COVID-19 pandemic significantly reshaped the transportation sector by having a remarkable and lasting impact on global travel patterns. Some key issues that emerged include increased public interest in zero-emissions mobility (ZEM), a surge in micro-mobility options, a temporary decline in public transit and air travel, and an increased curiosity around autonomous vehicles and technology. Other significant topics include the digitization, automation, and cybersecurity of our transportation infrastructure, increased awareness of supply chain disruptions, transportation equity, and an increased awareness towards safety, accessibility, and equity on California roads. These themes have pushed the transportation sector into exciting new spaces and motivated PATH and Caltrans to expand into novel areas of research and development.

Zero-Emissions Mobility

As the effects of climate change and carbon emissions continue to attract worldwide attention, consumers are becoming increasingly interested in and adopting environmentally-friendly and zero-emissions-mobility (ZEM) transportation options such as walking, electric cars, and bicycles. To motivate buyers and encourage EV acceptance, the federal government and the state of California currently offer a range of incentives for EVs, including tax credits, rebates, and HOV lane access. In 2021, CARB approved new regulations requiring truck manufacturers to sell increasing numbers of zero-emissions vehicles in the state. The advancements made by California in achieving zero emissions mobility between 2021 and 2022 have shown encouraging signs, as the state has established ambitious goals and taken tangible measures to facilitate the shift towards a cleaner transportation system. The promotion of EVs has led to a noticeable acceleration in electric vehicle purchases (25% of new light-duty vehicle sales) and increased interest in micro-mobility options. Bike-sharing and e-scooter services expanded in urban areas, providing personal transportation alternatives to public transit. The rise of e-commerce also had a significant impact, as seen by increased demand for delivery services and more

delivery vehicles on the road. These changes highlight the need for resilient transportation systems and digitalization and automation in supply chains.

The 2021 Infrastructure Investment and Jobs Act (IIJA) and the 2022 Inflation Reduction Act (IRA) are key investments in American infrastructure. [4] In March 2023, another groundbreaking multi-billion dollar program funding the development of electric vehicle (EV) charging infrastructure and alternative-fueling infrastructure in communities nationwide and along designated highways, interstates, and major roadways was established. The U. S. Department of Transportation's new Charging and Fueling Infrastructure (CFI) Discretionary Grant Program represents a crucial milestone in constructing a national network comprising 500,000 public EV charging stations. By facilitating widespread access to EV charging facilities, this program aims to significantly contribute to the reduction of national greenhouse gas emissions, aiming to achieve a 50–52% decrease by the year 2030. [5]

In November 2021, thirty nations and six major automakers, including Ford and GM, signed a pledge announcing plans to stop the global sale of new gas and diesel vehicles by 2040 and by 2035 in leading markets. Although the United States did not sign the agreement, the states of California and Washington added their signatures to the pact.[6] This move aligns with Caltrans' strategic goal to "lead climate action" and to reduce "GHG emissions from transportation to 80 percent below 1990 emissions levels by 2050."[7] California aims to put 5 million zero-emission vehicles on the road by 2030 and Governor Newsom has committed to requiring that sales of all new passenger vehicles be zero-emission by 2035. [8]

Greenhouse Gas Emissions (GHG)

California set ambitious goals to reduce its GHG emissions and is implementing various policies and programs including a cap-and-trade program, renewable energy mandates, and incentives for electric vehicles.[9] The aim is to reduce emissions to 40% below 1990 levels by 2030 and to achieve carbon neutrality by 2045. The transportation sector is one of the largest contributors to anthropogenic greenhouse gas (GHG) emissions. According to the California Air Resources Board (CARB) GHG Emission Inventory, transportation accounted for the largest portion (~38%) of total U.S. GHG emissions in 2021 (see Fig. 3). Cars, trucks, commercial aircraft, and railroads, among other sources, all contribute to transportation end-use sector emissions. According to CARB's data, light-duty vehicles account for 27.3% of total GHG emissions, medium- and heavy-duty trucks account for 8.3%, shipping accounts for 1.0%, aircraft account for 0.9%, rail accounts for 0.3%, and unspecified sources account for 0.3%. In comparison, transportation accounts for just 28% of total GHG emissions in the U.S., highlighting California's reliance on transportation (see Fig. 4).

[4] Transportation Trends 2022–23 (deloitte. com)
[5] Biden-Harris Administration Opens Applications for First Round of $2. 5 Billion Program to Build EV Charging in Communities & Neighborhoods Nationwide (govdelivery. com)
[6] Six Major Automakers Agree to End Gas Car Sales Globally by 2040 (caranddriver. com)
[7] Caltrans Unveils Vision for Future of Transportation | Caltrans
[8] California Enacts World-Leading Plan to Achieve 100 Percent Zero-Emission Vehicles by 2035, Cut Pollution | California Governor
[9] Fast Facts on Transportation Greenhouse Gas Emissions | US EPA

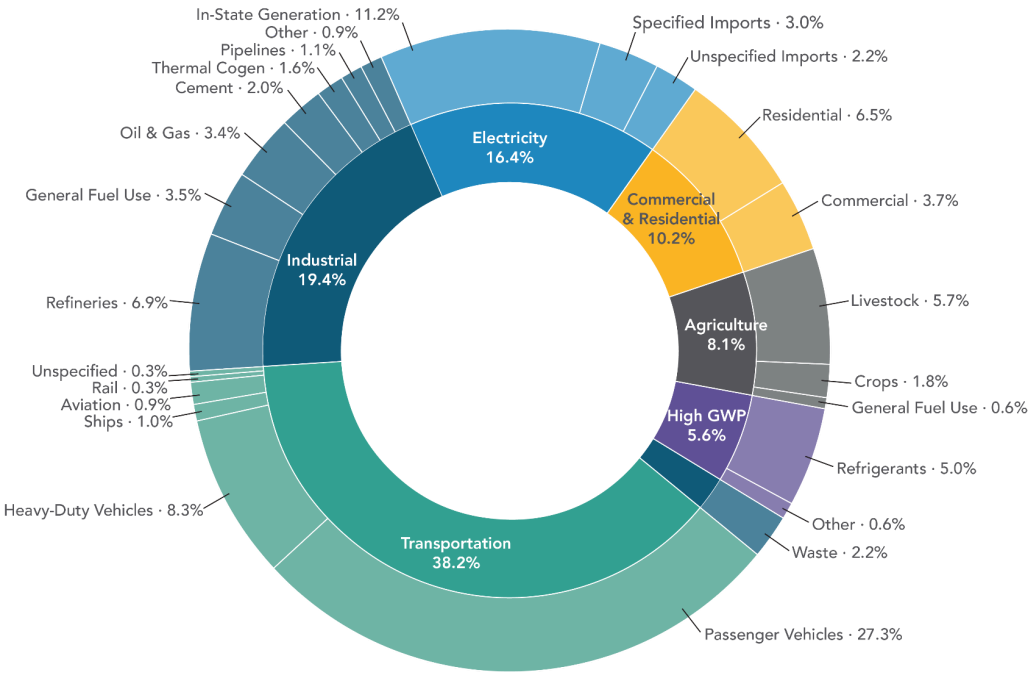


Figure 3. 2021 California Greenhouse Gas Emissions Inventory: Source: https://ww2.arb.ca.gov/ghg-inventory-graphs

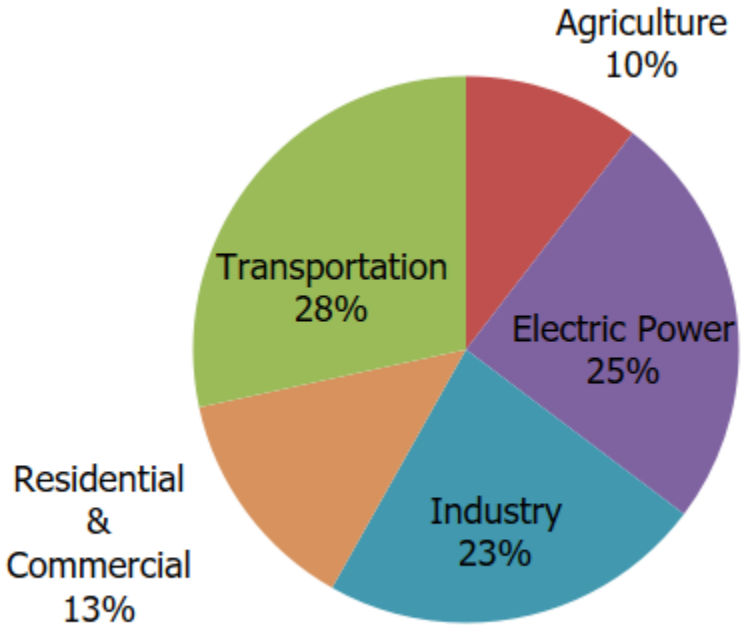


Figure 4. 2022 U.S. Greenhouse Gas Emissions inventory by economic sector. Source: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Economy

California's diverse economy encompasses many industries dependent on a reliable transportation network. Key sectors contributing significantly to California's economy include technology and innovation, entertainment, agriculture, health, tourism and hospitality, aerospace and defense, international trade, and financial services. These sectors, among others, contribute to California's position as the world's fifth-largest economy, generating significant employment opportunities and driving economic growth. Despite a significant drop in numbers culminating in a low of 15,646,706 jobs in May 2020, California has added 2,850,093 jobs since then, according to the CPS survey.[10]

Public Transit

During the pandemic, the transportation industry suffered significant losses due to reduced air and public transit demand, as society feared the risk of catching and spreading the virus. Recent efforts to expand public transit ridership include the Resilient and Innovative Mobility Initiative (RIMI), a UC ITS initiative bringing together university experts, policymakers, public agencies, industry stakeholders, and community leaders to inform the state transportation systems immediate COVID-19 response and recovery needs while establishing a long-term vision and pathway to innovative mobility in California. Reducing vehicle miles traveled is a significant challenge for California. Reliance on personal vehicles, urban congestion, long commutes, and limited housing options are significant reasons this problem has yet to be resolved. Making public transit an attractive alternative to a private vehicle is still an ongoing issue. Still, the shift towards public transportation can be supported by informing the public about the existing competitive options. In 2018, the California Air Resources Board (CARB) approved the Innovative Clean Transit regulation in 2018 which set a statewide goal for California's public transit agencies to transition to an all zero emission bus fleet by 2040. When fully implemented it is expected to reduce GHG emissions by 19 million metric tons from 2020 to 2050—the equivalent of taking four million cars off the road. [11]

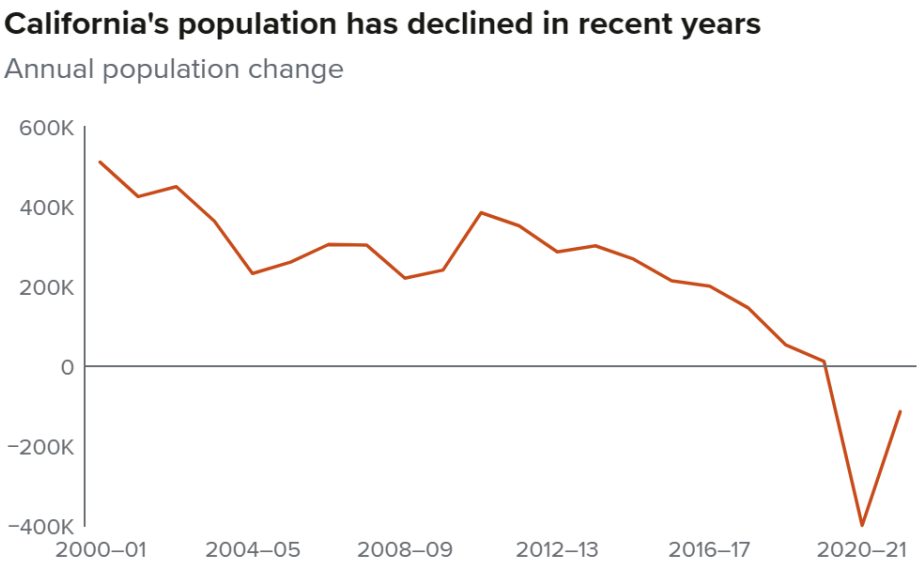
Mobility as a Service (MaaS)

Mobility as a Service (MaaS) encompasses a shared goal of transforming the public's concept of vehicle ownership. Its fundamental purpose is to provide travelers with access to various transport modes on a per-trip basis. To accomplish this, MaaS establishes a streamlined connection between users and mobility services, often leveraging a technologically advanced platform such as a smartphone app and its underlying infrastructure. As a unified interface, MaaS enables users to efficiently plan, book, and pay for various mobility services catering to their travel requirements. As a result, the responsibility of integrating various modes of transportation falls upon the MaaS provider, relieving the traveler of this burden.

Population Shifts

After reaching its peak of 39.6 million residents in January 2020, California experienced a decline of 600,000 people as of July 2022, primarily observed during the initial year of the pandemic. This decrease can be "attributed to a combination of factors, including increased mortality rates, significant drops in international migration, and a rise in residents relocating to other states." [12]

[10] California Job Growth | Department of Numbers (deptofnumbers. com)
[11] California Transportation Plan 2050
[12] California's Population - Public Policy Institute of California (ppic. org)



Source: California Department of Finance; 2023

Figure 5. California's Population 2000-2021

However, according to the CTP 2050, by 2050 the population is expected to grow to over 45 million residents. This growth will increase congestion and GHG emissions and strain existing infrastructure. The Climate Action Plan for Transportation Infrastructure (CAPTI) was adopted to combat these upcoming challenges in July 2021. The plan outlines the state's proposal to allocate billions of discretionary transportation funds yearly to actively address and adapt to climate change while prioritizing public health, safety, and equity. CAPTI expands upon Governor Gavin Newsom's executive orders from 2019 and 2020, which specifically aimed to reduce greenhouse gas emissions in the transportation sector. Transportation-related emissions contribute over 40 percent of total emissions, and CAPTI aims to achieve significant progress in reducing these emissions. [13]

Supply Chain Disruptions

The rise of e-commerce is another substantial shift that has emerged in transportation. As nations went into lockdown and social distancing measures were implemented, online shopping skyrocketed - leading to a surge in demand for delivery services - increasing the number of delivery trucks and vans on the road. The increase in demand, of course, has also affected the supply of goods. Unfortunately, the supply chain disruptions, including substantial raw material shortages and shipping delays, underscored the value of resilient transportation systems. Over the past few years, businesses and governments have seen the need for digitalization and automation to improve the efficiency and flexibility of their supply chains. The emergence of new digital technologies has enabled the supply chain to be managed more efficiently. These technologies actually increase and enhance the ability to optimize planning, sourcing and procurement strategies.

[13] Climate Action Plan for Transportation Infrastructure (CAPTI) | CalSTA

Autonomous Vehicles

Autonomous vehicle (AV) development continued at PATH and in the private sector as advanced driver-assistance features integrated into vehicles has become the norm. There is a wide range of vehicle automation concepts, ranging from adaptive cruise control systems that control a vehicle's speed and following distance to fully automated systems that take on the entire dynamic driving task. Fully automated systems in vehicles remains a controversial issue since many believe the technology has not been developed enough for widespread adoption. However, as research and development continue to swiftly grow, AVs are poised to change the transportation landscape in the near future. Automakers continue incorporating advanced driver-assistance features into their vehicles, and the technology becomes more advanced with every iteration.

California is home to numerous companies developing AV technology, and the state has some of the world's most engaged government agencies regarding testing AVs on public roads. The California DMV Autonomous Vehicle Testing program establishes regulations governing autonomous vehicle testing and deployment on California roads to encourage innovation and promote road safety. To date, the DMV has issued over 60 AV testing permits, and the state is investing in AV infrastructure such as charging stations and data centers. In California, manufacturers testing autonomous vehicles must report any collision resulting in property damage, bodily injury, or death within ten days of the incident. As of April 3, 2023, the California DMV has received 577 Autonomous Vehicle Collision Reports. One hundred fifty-five reports alone were made in 2022 and 117 in 2021. [14] Autonomous vehicle manufacturers that are testing vehicles in the Autonomous Vehicle Tester (AVT) Program and AVT Driverless Program are required to submit annual reports to share how often their vehicles disengaged from autonomous mode during tests (whether because of technology failure or situations requiring the test driver/operator to take manual control of the vehicle to operate safely). There were 12 total reports - six in 2022 and six in 2021. As more AVs make their way onto California roads, timely and effective research efforts should also accelerate to ensure safety standards are met. PATH researchers are currently conducting a five-year study partnering with the Department of Motor Vehicles (DMV) to understand California AV regulations, discussed later in the report.

In August 2022, California introduced the "Autonomous Vehicle Strategic Framework," a comprehensive planning document resulting from the collective efforts of multiple state agencies and stakeholders. This framework outlines a unified vision for the state, focusing on the optimal integration of autonomous vehicles (AVs) into our daily lives and the broader transportation ecosystem while ensuring safety and maximizing public benefits. With this strategic framework, California establishes a clear direction for the responsible and beneficial integration of autonomous vehicles, focusing on a sustainable future that prioritizes the well-being and prosperity of its residents.

Key points from the framework include:

- Vision: California aims to harness innovation to deploy zero-emission autonomous vehicles safely and unlock their full potential in mobility, safety, job creation, equity, health, environment, land use, and overall quality of life.
- Guiding Principles: The strategic framework is built upon a set of guiding principles that encompass important aspects such as environmental sustainability, equity, the creation of high-quality jobs, inclusivity, partnerships, public health, livability, safety, and the shared economic benefits that AVs can bring.

[14] Autonomous Vehicle Collision Reports - California DMV

Safety, Equity, and Accessibility

Equity in transportation refers to ensuring fair and equal access to transportation services for all members of society regardless of their socioeconomic status, age, gender, race, or abilities. This includes providing affordable, safe, and efficient transportation options to disadvantaged communities, improving access to jobs, education, and essential services, and reducing the impacts of transportation on the environment. Overall, transportation safety remains a key priority for California, and the state is taking steps to improve safety across all modes of transportation. However, there are still many challenges and obstacles to overcome, and ensuring the safety of all road users will require ongoing collaboration and investment from public and private stakeholders.

Safety

Safety has always been a cornerstone of the foundation of PATH. Safety in transportation refers to policies, practices, and measures that aim to prevent accidents, injuries, and fatalities in various modes of transportation, including road, air, rail, and sea. It ensures that all vehicles, equipment, infrastructure, and routes are designed, constructed, and maintained to meet safety standards and guidelines. Transportation safety in California is a complex and multifaceted issue that involves several modes of transportation, including roads, highways, public transit, biking, and walking. Motor vehicle collisions are a leading cause of unintentional injuries and deaths among all age groups in the United States. In 2022, an estimated 7,500 pedestrians were killed by drivers last year – the highest number since 1981",[15] according to the Governors Highway Safety Association organization. Reckless driving, distracted driving, road rage, and self-driving cars –these all have the potential to be deadly. Unfortunately, car accident fatalities also continue to rise. According to the National Highway Traffic Safety Administration (NHTSA), there were 42,915 motor vehicle fatalities in the U. S. last year – an average of 117 people per day and the highest overall number in 16 years. Data from NHTSA and many other studies suggest that over 90% of traffic accidents are due to human driver error. Other safety and privacy issues, such as fears of unauthorized recordings inside a smart vehicle remain a legitimate and concerning subject.

PATH continues to facilitate safer roadways and vehicles and provides ongoing support and guidance to Caltrans regarding this important issue. Many of PATH's project themes overlap, such as in the case with the project "Drivers' Responses to Eco-driving Applications: Effects on Fuel Consumption and Driving Safety", which investigates drivers' responses when using Eco driving applications, the effects on fuel savings and emission reduction, and the associated safety impacts through a simulated driving experiment involving a local roadway with signalized intersections and freeway stop-and-go traffic.

Equity

Achieving transportation equity requires addressing systemic inequalities and acknowledging different user groups' diverse needs and preferences. An inclusive approach to designing and implementing technology in AVs is essential to ensure it is accessible to all people, regardless of age, wealth status, or physical ability. In the ongoing PATH project, "Digital Mobility Assistant for Disabled Transit Users," PATH researchers are working with the disabled community of Contra Costa County through the center for Independent Living Resources of Solano and Contra Costa Counties to understand disabled traveler's needs, restrictions, preferences, and points of interest

[15] Drivers Hit and Killed More Than 7,500 Pedestrians Last Year, Most Since 1981, New Projection Shows | GHSA

(POIs). PATH is building a knowledge graph (KG) with this data along with information from mobility services including transit, paratransit and private companies such as Uber WAV with their schedules, coverage areas, cost, etc. The goal of this research is to build a working prototype system that would help generate a travel plan for a disabled person using available mobility options that include transit and paratransit but is not limited to those.

Transportation Accessibility

Transportation Accessibility is the measure of the ease of reaching destinations or activities within an area. It can be affected by factors like transportation options, transportation connectivity, and personal mobility. One promising solution is the advancement of shared automated vehicles (SAVs). Accessibility is an important issue for California and PATH. Dr. Peggy Wang is leading the project "Transportation Accessibility and Adoption of Shared Automated Vehicles by Disabled Travelers" to evaluate the potential for Automated Vehicle (AV) technologies to improve the mobility of people with disabilities. The project reviews the current literature on the transportation needs and challenges of people with disabilities regarding AVs, the prospective adoption of Shared Automated Vehicles (SAVs) for them, and their broader mode of transportation choices when SAVs become available. This research underpins the notion that AV technology will likely save lives and provide more accessible mobility for everyone.

Zero Deaths

“Vision Zero” is an approach to traffic safety recognizing that even one traffic-related death is too many and that traffic fatalities are preventable with the right policies, technologies, and strategies. The goal of the initiative is to create a transportation system that is safe and accessible for everyone, regardless of age, income, or ability.[16] The Road to Zero Coalition is managed by the National Safety Council and aims to reduce traffic-related fatalities and serious injuries on roads to zero by the year 2050. This initiative includes various partners including FHWA and NHTSA and aligns closely with Caltrans' strategic goal of Safety First. In 2018, a Zero Traffic Fatalities Task Force was established in California after Assembly Bill 2363 was signed to evaluate the ways speed limits are set and proposed policies to reduce traffic fatalities to zero. In August 2020, they produced a report outlining steps to make roadways safer in California.

Emerging Technologies

Emerging technologies have the potential to transform transportation in California and beyond. However, their widespread adoption also raises challenges that must be addressed through collaboration between the public, government agencies, and private stakeholders.

- Artificial intelligence - AI technologies are profoundly impacting transportation across various domains, revolutionizing how we move people and goods. For example, AI is fundamental to detecting vulnerable road users and other objects in roadways. It has also been applied to control traffic lights within an urban roadway network, to reduce congestion. More recently, end-to-end AI has been applied to not just perceive roadway environments but also directly control vehicles. Finally, generative AI (the technology behind ChatGPT) is being used to generate simulation scenarios from real-world crash

[16] Road to Zero - National Safety Council (nsc. org)

reports as a means to test AV algorithms. Many of these advancements have been incubated at UC Berkeley in the Berkeley DeepDrive consortium.

- High-Speed Rail System - A future investment for California taxpayers includes a high-speed rail system, which will be among the first of its kind in the United States. The responsibility for the system's planning, design, construction, and operation rests with the California High-Speed Rail Authority. Once finished, the system will enable travel from San Francisco to the Los Angeles basin in less than three hours, reaching speeds of over 200 miles per hour. Its purpose is to connect the state's major regions, foster economic development and a cleaner environment, generate employment opportunities, and safeguard agricultural and protected lands. Eventually, the system will expand to include Sacramento and San Diego, covering 800 miles and featuring up to 24 stations. There is also a proposed statewide rail modernization plan in place, aiming to allocate billions of dollars toward enhancing local and regional rail lines to meet the state's transportation requirements of the 21st century. [17]
- Drones - Drone technology is also steadily advancing and has the potential to revolutionize transportation by enabling delivery services, aerial surveys, and emergency responses. California has been at the forefront of drone testing and innovation, with several drone companies based in the state and partnerships with government agencies and research institutions. Utilizing drone technology could help decrease carbon emissions, reduce stress, and improve safety by lowering the number of vehicles on the road.
- In-Road Vehicle Charging - A new charging solution drawing attention is in-road inductive charging. Inductive charging is a cordless power transfer that uses electromagnetic induction to provide electricity to chargeable objects such as vehicles and trains. In the near future, this could be a viable solution for electric vehicle charging and eliminate the need to stop for hours at a time to charge a personal vehicle. Alternative approaches include conductive charging technologies of battery swapping stations.
- Solar - Solar energy technology has progressed by leaps and bounds in just a few years. Recent advances include ultra-efficient solar cells, which are the photovoltaic components in solar panels that convert sunlight into electricity, solar panels that collect energy at night, and new perovskite solar cells that can efficiently charge vehicles when they are under the sun.
- Vehicle Sensors - Sensors play a vital role in an automated driving system (ADS) for perception, planning and decision, and motion and vehicle Control. Autonomous vehicles (AVs) primarily utilize a fusion of multiple vision cameras, radar sensors, LiDAR sensors, and ultrasonic sensors to perceive their environment and other sensors like Global Navigation Satellite System (GNSS), Inertia Measurement Units (IMUs), vehicle odometry sensors to determine their relative and absolute positions. These recent advancements may aid in reducing traffic congestion by navigating road users to alternative routes and help improve safety by decreasing collisions.

[17] High-Speed Rail in California - California High Speed Rail

These are a sampling of the developing technologies in California. More in-depth analysis can be found in the PATH white paper, "Emerging Technologies in Transportation,"[18] drafted by PATH and submitted to Caltrans in April 2023.

PATH Core Competencies (Thrust Areas)

PATH research and core competencies span across multiple thrust areas . PATH's Thrust Areas are aligned with Caltrans Strategic Goals and other state legislation that has recently passed. Note that these thrust areas overlap. A summary of our projects can be found at the end of this report. Our thrust areas are:

- Connectivity and Automation
- Transportation System Optimization (formerly Traffic Operations)
- Zero Emissions Mobility
- Digital Transportation Infrastructure (AI; BDD)

Connectivity and Automation

The themes of connectivity and automation often work in tandem and facilitate innovative opportunities. A connected infrastructure covering intersections and roadways opens up an extensive range of possibilities to progress California's strategic objectives of safety, equality, and climate action. Intersections, being inherently multimodal, can be designed to enhance the ease and appeal of transit and active transportation like biking and walking. As transportation moves towards increased use of connected and automated vehicles, California must continue to address the challenges of mixed autonomy and human factors.

Connectivity

Connectivity refers to integration and information exchange between transportation system elements. This includes the ease with which different modes of transportation can be interconnected and integrated to create a seamless, efficient, and accessible network. Connectivity is rapidly evolving, encompassing a wide range of features and applications. This includes the availability of multiple transportation options, such as roads, railways, air travel, waterways, and pedestrian and cycling infrastructure, as well as adequate infrastructure and services to facilitate the movement of people and goods between different modes of transportation. As noted in the whitepaper presented to Caltrans in Spring 2023, "Emerging technologies in Transportation," connectivity also involves "using technology, such as real-time data and communication systems, to improve the coordination and optimization of transportation networks. In today's interconnected world, the access to and widespread use of smart devices has transformed how we interact, communicate, and collaborate. " One of the most significant benefits of connectivity is the ability to gather and store data about vehicles. This data can be used to inform vehicle owners about their vehicle's status, such as odometer readings, charge status, and mechanical information. OEMs can also use this data to provide automated alerts for maintenance needs, perform vehicle software updates like a smartphone, or even remotely deploy fixes for safety recalls "over the air" (OTA).

Under the sponsorship of Caltrans, California PATH has been conducting efforts developing an Integrated Dynamic Transit Operation (IDTO) System for multimodal suburban transit, in

[18] Emerging Technologies in Transportation – California PATH

collaboration with Contra Costa Transportation Authority (CCTA) and Tri-Delta Transit. The IDTO system aims at supporting enhanced transit operations by dynamically holding vehicles at bus stops to meet with connecting passengers (Transfer Connection Protection or T-CONNECT), adjusting transit routing to pick up passengers not on regular routes or avoiding congestion regions (Dynamic Dispatch or T-DISP), facilitating first-mile and last-mile shared riders (Dynamic Rideshare or D-RIDE), and providing travelers with real-time trip update information. All these applications are integrated into the IDTO framework and operate in real-time to enable enhanced connectivity, more convenient public transit service and improved service quality for the suburban travel public.

Another advantage of connectivity is the ability to deliver over-the-air (OTA) software updates, enabling new features and security patches to be seamlessly applied to vehicles. This stream of software-driven updates and enhancements leads to an improved consumer experience, extending the vehicle's lifespan and contributing to environmental benefits. Connectivity also opens up the door to new infotainment and entertainment features, such as streaming media and live traffic updates. Overall, connectivity plays a vital role in enhancing mobility, reducing congestion, and improving the efficiency and effectiveness of transportation systems.

Connected Vehicles (CVs)

CVs use wireless communication to share information with other vehicles, infrastructure (such as traffic signals), and road users. Some examples of CVs are:

- Vehicle-to-Vehicle (V2V): communication between vehicle
- Vehicle-to-Infrastructure (V2I): communication between vehicles and infrastructure such as traffic signals, work zones, etc.
- Vehicle-to-Pedestrian (V2P): communication between vehicles and pedestrians, and
- V2X (vehicle-to-everything): allows vehicles to communicate with their surroundings, including other vehicles, infrastructure, traffic lights, parking spaces, cyclists, and pedestrians.

Dr. Kun Zhou was the Principal Investigator of the project, "Collect Data using Connected Vehicles (CV) for Real-Time and Future Use" under Task 3717 for Caltrans. This research addresses the technology gap in gathering useful information (like travel speed, origin and destination, vehicle classification, and vehicle lane position) from CV data and integrating this new information with TMC operations through real-time CV data collection, analysis, and information dissemination between connected infrastructure and the TMC. The end goal is to monitor the traffic condition on the road and to optimize the throughput in real-time.

Automated Vehicles (AVs)

Automated Vehicles (AV) are driverless or automated driving assistance systems that utilize artificial intelligence and/or computer algorithms to operate the vehicle, with various levels of human supervision. California PATH has been involved in the research, development, and testing of connected and automated vehicles since its inception in 1986. Developing and advancing adaptive cruise control (ACC) and cooperative adaptive cruise control (CACC) systems in cars and trucks have been a key element of PATH’s research portfolio. In 2021, PATH provided Caltrans leadership with a vision and tactical strategy in preparation for CAV deployment in California with the Caltrans Connected and Automated Vehicles Strategic Plan. Another PATH project,

"System Impact of Connected and Automated Vehicles - An Application to the I-210 Connected Corridors Pilot", was to develop an integrated platform to incorporate CAVs into microsimulation and evaluate their system impacts on large-scale transportation networks. Overall, the goal of this project was to provide public agencies useful tools to better understand the system impact of CAVs and help them perform long-term planning.

In March 2022, PATH published the document through the Transportation Research Board, “Automated Vehicles Industry Survey of Transportation Infrastructure Needs,” designed to answer the question, “What transportation infrastructure improvements do AV manufacturers believe will facilitate and improve AV performance?” In this research endeavor, an extensive survey was conducted within the autonomous vehicle industry, encompassing multiple facets of infrastructure. These aspects included both physical and digital infrastructure, infrastructure maintenance requirements, specifications and standards for roadways, support from infrastructure policies, deployment timelines for AVs, data sharing protocols for repair and maintenance purposes, as well as opportunities for collaboration and engagement with infrastructure owner-operators (IOOs). The goal was to initiate dialogue between the AV industry and state DOTs by connecting key stakeholders.

The ongoing project, "Technical Support to California DMV on Automated Vehicle (AV) Regulations," provides the Department of Motor Vehicles with valuable insight and support into AV technologies in California. PATH is assisting the DMV in analyzing the data provided by the companies that are testing AVs on California public roads to assess the maturity of the technology and providing technical reviews of the applications that the companies submit when they apply for permits to test without drivers or to put AVs into regular public operation. Dr. Steven Shaldover, a veteran PATH researcher with 50 years of experience in research and development on road vehicle automation, helms this project.

Connected and Automated Vehicles (CAVs)

Connected and Automated Vehicles (CAVs) technology can help reduce traffic accidents and improve the efficiency of transportation systems. CAVs leverage both Connected Vehicle (CV) and Automated Vehicle (AV) technologies by communicating with nearby vehicles and infrastructure to help make driving decisions.

Transportation system optimization

Transportation system optimization involves maximizing the efficiency and effectiveness of various transportation modes such as roads, railways, airways, and waterways. Optimization may involve installing traffic management systems, setting up intelligent transportation systems (ITS), and utilizing advanced technology such as real-time traffic data, analytics, and artificial intelligence. By optimizing transportation systems, cities and businesses can improve their overall transportation performance, reduce costs, and enhance the travel experience for passengers and goods.

Smart cities

Smart Cities and transportation system optimization are interrelated topics. "Smart cities" refers to using advanced technologies and data analytics to improve the efficiency, safety, and sustainability of civic infrastructure, including transportation systems within urban areas. The concept involves integrating various modes of transportation, including public transit, cycling, walking, and private vehicles, using intelligent transportation systems (ITS) and connected

devices. Smart city transportation systems rely on a wide range of technologies, such as sensors, GPS, and mobile devices to collect data on traffic flows, parking, and public transportation usage. This data is then analyzed to provide insights into transportation patterns and inform decisions on optimizing transportation infrastructure and services. Examples of smart city transportation initiatives include intelligent traffic management systems, real-time transit information and payment systems, bike-sharing programs, and electric vehicle charging infrastructure. These initiatives aim to reduce traffic congestion, promote sustainable transportation modes, and improve safety for all road users.

Cybersecurity

Cybersecurity is a significant concern for the transportation sector. While vulnerabilities and hacking cases in transport systems have already been documented, guidelines and methods for addressing cybersecurity in the transportation sector are continually evolving. PATH has published a report examining cyberattack trends and cybersecurity, impacts on transportation, vulnerabilities, and attack vectors (including real-world instances of these attacks), and potential steps to address our transportation systems' cybersecurity challenges.

Zero Emissions Mobility (ZEM)

Zero Emissions Mobility (ZEM) refers to the use of vehicles that emit little to no harmful pollutants or greenhouse gasses into the environment. These vehicles run on alternative energy sources such as electricity, hydrogen, or biofuels, reducing the dependence on fossil fuels. They offer several benefits, including lower carbon emissions, reduced air pollution, and improved public health. Many countries and cities aim to promote zero-emissions mobility by introducing policies and incentives to encourage the adoption of zero-emissions vehicles. Additionally, investment in infrastructure, such as charging stations and hydrogen fueling stations, also plays a critical role in assisting the widespread adoption of zero-emissions mobility. The difficulty in reducing carbon emissions in the transportation sector is significant and should be considered. Climate change, particularly carbon emissions, continues to be a major concern for the transportation sector. Shifts in consumer behavior and a desire for more environmentally-friendly transportation options have emerged.

Supporting sustainable transportation, such as expanding public transit and electrifying vehicles, is a primary goal for Caltrans and PATH. PATH continues to focus our attention on this issue by making it a priority research area. PATH has several research projects currently in the field of zero-emissions mobility. In the completed project, "SBIR Phase II: Intelligent Planning and Control Software for EV Charging Infrastructure", the overall goal was to develop, build and commercialize an intelligent planning and control software for EV charging infrastructure for transit buses, commercial fleets and private cars.

Zero-Emissions Vehicles (ZEV)

The environmental benefits of zero-emission vehicles (ZEVs) have boosted sales of electric cars and bicycles, leading to a substantial increase in the adoption of electric vehicles worldwide. Multiple research endeavors in this field focus on energy consumption and modeling, as well as alternative modes of transportation, including bicycles, public transit, and micro-mobility. As battery costs decline and EVs become more affordable, EV acceptance and demand should continue to increase.

Micro mobility

As discussed earlier, public health, gas prices, and environmental concerns altered consumer behavior. The acceleration of electric vehicle purchases was one benefit, and an increased interest in micro-mobility options was another. As COVID-19 spread, people looked for alternative options besides public transport, which took a massive hit during the pandemic. Personal vehicles became a more appealing option than public transportation, increasing demand for cars, bikes, and scooters. The growth of bike-sharing and e-scooter services in urban areas exploded.

Digital Transportation Infrastructure

Unlocking new possibilities in transportation depends on effectively utilizing Digital Transportation Infrastructure, serving as the foundation for a robust data exchange capability. DTI acts as a force multiplier and empowers Caltrans to leverage private vendor insights and sensor technologies to develop a more comprehensive understanding of traffic patterns. Immediate integration of these insights into Caltrans decision-making would enhance the power of DTI. PATH categorizes Berkeley Deep Drive and Artificial Intelligence projects within the DTI area of interest.

AI Technology

Developments of machine learning and AI technologies continue to advance at astonishing speed and have led to tremendous breakthroughs in fundamental theories and applied techniques. BDD is mostly involved in robotics and autonomous vehicles but the fundamental and applied AI research being developed and explored at BDD could be adopted for a variety of applications.

Demonstrations and proof-of-concept experiments

To advance from theory to practice, it is essential to undertake demonstration projects and proof-of-concept experiments. As noted in the PATH Research Roadmap (2023), “these endeavors harness the potential of Digital Transportation Infrastructure (DTI), sensing infrastructure, and other resources to assess novel technologies. The knowledge gained from these undertakings allows Caltrans to make sound, strategic investments in technology aligning with state objectives to enhance safety and equality, lead climate action, and forge robust multimodal transportation networks. The collaborative approach between different government jurisdictions and agencies also sets a positive precedent for partnership and cooperation.”

Truck Platooning

Truck platooning involves linking two or more trucks in a convoy, using technology to coordinate their movements and maintain a close distance between them. A human driver drives the lead truck, while the following trucks are driverless - enabled by connected & automated vehicle technology. This allows the trucks to travel more efficiently, as they can draft behind one another, reducing wind resistance and improving fuel efficiency. The "Truck Platooning Early Deployment Assessment: Phase 2" project, spearheaded by Dr. Xiao-Yun Lu and supported by John Spring, Dr. Hao Liu, and others, was intended to discover any gaps in research toward the deployment of partially automated truck platooning for daily freight movement during long-distance hauls. This research aims to demonstrate that truck platooning can provide significant fuel savings and emissions reductions while maintaining safety and improving

efficiency in the freight transportation sector. The program also explores potential policy and regulatory changes needed to facilitate the widespread adoption of truck platooning technology in California and beyond.

Active Projects

(completed or being executed from July 2020-June 2023)

Many of PATH's active, recently completed, and upcoming projects have cross-cutting themes and can be categorized across multiple PATH Thrust Areas. We list these projects next, categorized under their main thrust area. The projects included below include projects administered during the FY 2021-22 fiscal years as well as currently active projects. A distribution of sponsored project funding by thrust area is also provided in Figure 6.

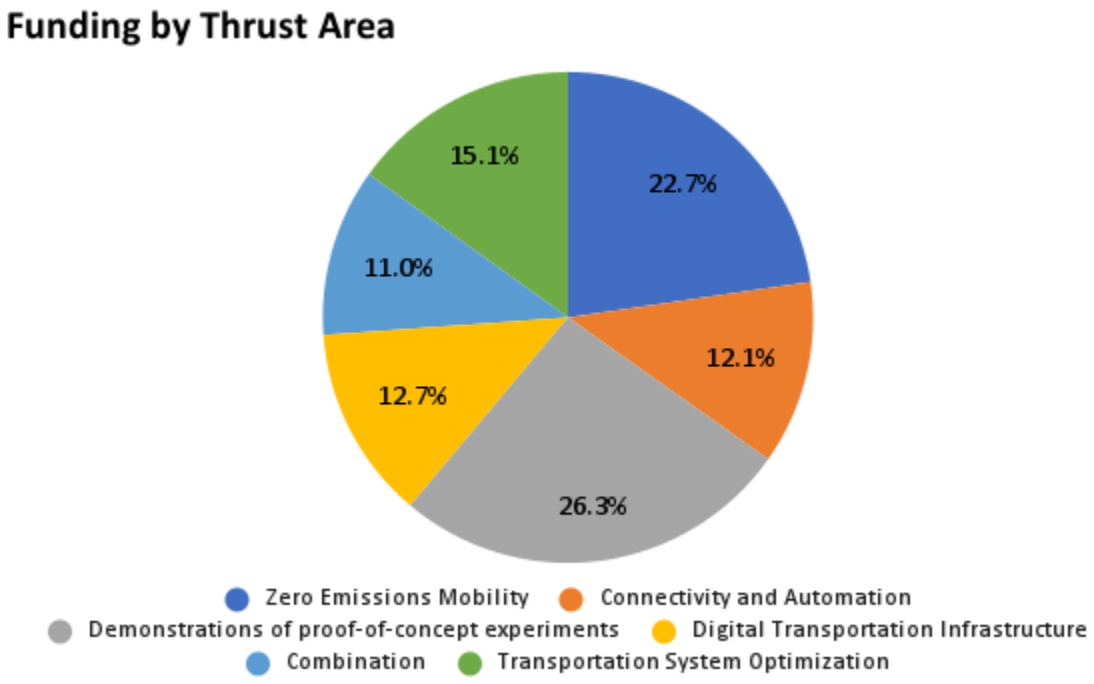


Figure 6. Distribution of PATH funding by Thrust Area.

Connectivity and Automation

White Paper: Paths for the Rollout of Connected and Automated Vehicles – This project will produce an exploratory white paper on various aspects of the rollout and adoption of CAVs. In producing the white paper, the researchers will first create a descriptive list of all current and planned CAV-related testbeds, pilot projects, and experimental deployments in California. Second, the researchers will conduct outreach with stakeholders engaged in near-term CAV deployments to understand their perspectives, needs, and goals. Stakeholders – including key public agencies and private stakeholders – will also be asked about their interest in using CAVs to achieve achieve traffic and environmental policy goals, to estimate traffic and environmental performance measures, to reimagine allocation of capacity among transit and automated/non-automated modes, and to deploy CAV fleets that simultaneously improve mobility services and traffic outcomes.; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $102,000.00; Date Completed: 2023-06-30; Principal Investigator: Bayen, Alex*

System Impact of Connected and Automated Vehicles - An Application to the I-210 Connected Corridors Pilot – The primary goal of Dr. Qijian Gan's project, "System Impact of Connected and

Automated Vehicles - An Application to the I-210 Connected Corridors Pilot", is to develop an integrated platform to incorporate CAVs into microsimulation and evaluate their system impacts on large-scale transportation networks. The proposed platform will incorporate the most appropriate CAV models/applications into Aimsun using the available Software Development Kits and allow users to explore different scenarios. In particular, the ACC/CCAA module will be used to control AV/CAV's longitudinal movements, and the V2X communications module will be used to enable the message communications among intersections equipped with RSUs and CVs/CAVs equipped with OBUs. Overall, the outcome from this project will provide public agencies useful tools to better understand the system impact of CAVs and help them perform long-term planning; *Project Sponsor: Caltrans; Funding Amount: $200,000.00; Date Completed: 2021-12-31; Principal Investigator: Gan, Qijian*

Caltrans Connected and Automated Vehicle (CAV) Strategic Plan – The purpose of this project is to define a vision and tactical strategy Caltrans leadership in preparation for CAV deployment. A number of transformational CAV technologies promise to have a profound impact on traffic operations and safety. At the same time, the research, development, and market penetration of these technologies are accelerating rapidly. Caltrans has a strong interest in preparing for the fast moving evolution in CAV.; *Project Sponsor: Caltrans; Funding Amount: $400,000.00; Date Completed: 2021-12-29; Principal Investigator: McKeever, Ben*

Development and Demonstration for Integrated Dynamic Transit Operations System, Phase II+ – Transit system were established upon the framework of fixed routes, fixed schedules, and almost-fixed ticket prices. To attract travelers from private driving, transit systems need to be flexible and dynamic. Integrated Dynamic Transit Operation (IDTO) applications show great potential to improve transit service – offering reduced travel time and improved connectivity. This project, an extension of prior Caltrans sponsored work, will test a fully functional IDTO system that delivers improvements to suburban transit services. The IDTO algorithms and user apps are developed to allow holding at bus stops to meet with connecting passengers (Connection Protection or T- CONNECT); *Project Sponsor: Caltrans; Funding Amount: $400,000.00; Date Completed: 2022-05-31; Principal Investigator: Meng, Joshua*

Connection Protection for CCTA MOD Project – PATH is a subconsultant of Advanced Mobility Group (AMG). The CCTA Mobility-On-Demand (MOD) Project aims to improve regional network integration and the traveler experience through the implementation of Connection Protection (CP) strategies within the MOD platform; *Project Sponsor: Contra Costa Transportation Authority; Funding Amount: $101,000.00; Date Completed: 2024-05-15; Principal Investigator: Meng, Joshua*

Solano Express (SE) Connection Protection Plan – This project analyzes and compares current schedules between local and regional transit operators to determine connection protection opportunities. PATH suggested a preferred list of connections according to historic estimated time of arrivals, ridership, alternative routes, total delay to the rider, and other relevant factors. PATH developed the application back-end and will continue to monitor and maintain the server. The Integrated Dynamic Transit Operation (IDTO) system will collect and archive data to support the evaluation of the IDTO system and services; *Project Sponsor: Solano Transportation Authority; Funding Amount: $50,000.00; Date Completed: 2022-12-31; Principal Investigator: Meng, Joshua*

Technical Support to California DMV on Automated Vehicle Regulations – The objective of this project is to provide technical assistance to the CDMV in their evaluation of third party field AV field testing on the streets of California. This included the development of a performance data performance framework and data evaluation of the resultant information; *Project Sponsor: California Department of Motor*

Vehicles; Funding Amount: $200,000.00; Date Completed: 2023-03-31; Principal Investigator: Shladover, Steve

Technical Support to California DMV on Automated Vehicle Regulations – This ongoing project, "Technical Support to California DMV on Automated Vehicle (AV) Regulations", is providing the Department of Motor Vehicles (DMV) valuable insight and support into AV technologies in California. PATH is assisting the DMV in analyzing the data provided by the companies that are testing AVs on California public roads to assess the maturity of the technology and providing technical reviews of the applications that the companies submit when they apply for permits to test without drivers or to put AVs into regular public operation. This project is helmed by Dr. Steven Shladover, a veteran PATH researcher with 50 years of experience in research and development on road vehicle automation; *Project Sponsor: California Department of Motor Vehicles; Funding Amount: $499,956.00; Date Completed: 2024-06-15; Principal Investigator: Shladover, Steve*

Developing Analysis, Modeling, and Simulation (AMS) Tools for Connected and Automated Vehicle (CAV) Applications – The objectives of this task order are to: (1) develop AMS tools for the most prominent CAV applications; (2) incorporate these tools into existing AMS commercial products, improving the state-of-the-practice; and (3) conduct real-world case studies (practical implementation scenarios and real-world transportation networks) for the most prominent CAV applications – to better understand their impacts and deployment strategies/methods; *Project Sponsor: USDOT FHWA; Funding Amount: $193,191.00; Date Completed: 2020-09-21; Principal Investigator: Shladover, Steve*

Autonomous Vehicles Industry Survey of Transportation Infrastructure Needs – Automated vehicle (AV) deployment has the potential to bring about transformational changes to the transportation sector and society as a whole. A key question being asked by the agencies is: “What transportation infrastructure improvements or modifications do AV manufacturers believe will facilitate and improve AV performance?” Therefore, this project was designed to address this question through on-line questionnaire and follow-up interviews; *Project Sponsor: BDD; Funding Amount: $10,000.00; Date Completed: 2021-03-00; Principal Investigator: Chan, Ching-Yao*

Interaction and Communication between Pedestrians and Fully Automated Vehicles – This BDD project was aimed to (1) determine how other road users will be interacting with automated vehicles (AVs), (2) ensure public acceptance and trust in AVs, and (3) confirm that pedestrians and other road users are aware of the automated systems’ capabilities and limitations. In this project, we propose to explore the interaction between AVs and pedestrians in an urban driving environment; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Wang, Peggy*

Accessibility and Adoption of Shared Automated Vehicles by Disabled Travelers – This project aims to understand the transportation needs and challenges for people with visual impairment in California, impacts of SAV on accessibility, their future adoption of SAV, and the potential change to their transportation mode choices envisioning having access to SAVs. SB1 Funding. Automated vehicle (AV) technologies are expected to save lives and provide enhanced mobility for all people. In particular, shared automated vehicles (SAVs) could be an attractive means to provide more accessible transportation access for those who cannot drive or face significant barriers to driving. This project will review the literature (peer-reviewed and grey) published to date to identify existing research on the transportation needs and challenges for people with disabilities relative to SAVs, the potential for future adoption of SAVs in this population, and the potential change to their transportation mode choices

envisioning having access to SAVs; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $75,526.00; Date Completed: 2023-08-31; Principal Investigator: Wang, Peggy*

Implicit Communication of Automated Vehicles: Using Vehicle Movement Cues for Coordination with Pedestrians at Intersections – 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 design question. Rather, it is a complicated research question associated with other critical aspects of AV deployment, including safe operation domains, infrastructure upgrade for segregating VRUs from AVs, traffic regulation for mixed-mode of driving, and standardization and education. Human-factors researchers have implemented many studies to investigate the effects of using external human machine interfaces (eHMI), such as LED lights or text messages, to signal AV's intention (e.g., stopping, moving, starting) when interacting with the pedestrians at intersections. The research team has found that eHMI helped pedestrians to feel safer when interacting with the AVs, and it should communicate the intent and status of AVs without instructing people what to do. On the other hand, it was also found that vehicle movement patterns (e.g., vehicle speed, distance), instead of the eHMI, continued to be a significant cue for pedestrians to decide when to cross the intersections . Therefore, vehicle movement cues are suggested to be considered as the primary communication channel. Understanding where the vehicle movement cues are ineffective would help decide what information should be added and how it should be communicated; *Project Sponsor: BDD; Funding Amount: $101,250.00; Date Completed: 2022-05-31; Principal Investigator: Wang, Peggy*

Collect Data using Connected Vehicles (CV) for Real-time or Future Use (Task 3717) – Dr. Kun Zhou was the Principal Investigator of the project, "Collect Data using Connected Vehicles (CV) for Real-Time and Future Use" under Task 3717 for Caltrans. This research addresses the technology gap in gathering useful information (like travel speed, origin and destination, vehicle classification, and vehicle lane position) from CV data and integrating this new information with TMC operations through real-time CV data collection, analysis, and information dissemination between connected infrastructure and the TMC. The Basic Safety Message (BSM) and Probe Vehicle Data (PVD) message are most important sources of this data.The end goal is to monitor the traffic condition on the road and to optimize the throughput in real-time; *Project Sponsor: Caltrans; Funding Amount: $100,000.00; Date Completed: 2022-06-30; Principal Investigator: Zhou, Kun*

Connected Vehicle Application Development (Task 3287) – The objective of this program is to physically expand the CAV test bed in Palo Alto (an additional 20 intersections) and to expand its functionality (at each intersection) to include some of the recent USDOTCAV applications. In addition, this project will support the implementation of Smartmicro sensors (deployed in a parallel project) and evaluate their efficacy in expanding intelligent control strategies at low DSRC implementation; *Project Sponsor: Caltrans; Funding Amount: $475,000.00; Date Completed: 2022-01-31; Principal Investigator: Zhou, Kun*

Maintenance, Operations and Enhancement of V2X Communications Infrastructure Phase II – This proposed project is the second phase of California CV Test Bed Maintenance and Support. The objectives of this project are: 1) Keep California CV Test Bed fully operational and compliant with national CV standards, such as IEEE 802.11, IEEE1609.x, and SAE J2735; 2) Provide support to new users and on continued CV research, including corporations, start-ups, research organizations, and public agencies; and 3) Provide liaison to national network of CV Test-Beds, including data sharing, security and management, knowledge exchange, and coordination with national V2I deployment efforts such as V2I Deployment Coalition; *Project Sponsor: Caltrans; Funding Amount: $139,995.00; Date Completed: 2020-09-30; Principal Investigator: Zhou, Kun*

Maintenance, Operations and Enhancement of V2X Communications Infrastructure Phase III – California PATH has been devoting efforts to keep the California CV Test Bed fully operational and compliant with the latest national CV standards to support researching, testing, and demonstrating of CV technologies that can enhance the safety and mobility of our transportation system.; *Project Sponsor: Caltrans; Funding Amount: $300,000.00; Date Completed: 2025-10-31; Principal Investigator: Zhou, Kun*

MMITSS Phase 3 – Under this UVA contracted (Pool Fund Study award) project, Smartmicro sensors will be installed on three test bed intersections. These sensors emulate DSRC-equipped vehicles that provide input data for MMITSS. This enables intelligent control strategies at low levels of DSRC implementations; *Project Sponsor: University of Arizona; Funding Amount: $310,000.00; Date Completed: 2021-01-31; Principal Investigator: Zhou, Kun*

MMITSS 3 Extension for Additional Enhancements – The goal of this Phase III effort is to make deployment readiness enhancements to the MMITSS prototypes that were developed and field tested in Phase II. The readiness enhancements are focused on creating improved and "cleaned up", or mature application code that is hardware agnostic and interoperable or transferable regardless of the hardware vendors or products; *Project Sponsor: Caltrans; Funding Amount: $250,000.00; Date Completed: 2023-03-28; Principal Investigator: Zhou, Kun*

Support Deployment of RTCM Broadcasts – The goal of this project is to provide a one-stop source for the deployment of Real-Time Kinematic (a new GPS positioning technique) broadcasts. These broadcasts have the potential to deliver free lane-level vehicle positioning solution for CV's, therefore improving the effectiveness of CV applications and providing better safety and mobility for all modes of travel. Project Sponsor: Caltrans; Funding: $150,000; End Date: December 2021.; *Project Sponsor: Caltrans; Funding Amount: $150,000.00; Date Completed: 2021-12-31; Principal Investigator: Zhou, Kun*

Utilizing Connected and Automated Vehicles as Floating Sensors for Cooperative Traffic Control and Road Condition Monitoring (Task 3688) – The long-term objective of this program is to integrate data collected by CAV's with CV data that is communicated via the Basic Service Message – and to use both for intelligent traffic signal control. The first phase of the research on this project will focus on the development of a fused CV-CAV data stream that can be produced and communicated in real-time from a modified CAV; *Project Sponsor: Caltrans; Funding Amount: $400,000.00; Date Completed: 2022-06-28; Principal Investigator: Zhou, Kun*

Red Light Violation Warning over Cellular Network – For this particular project, PATH proposes to partner with SinWaves, Inc. to assess the impacts of different types of V2I communication on the red-light violation warning (RLVW) application. Findings from this project have the potential to advance intersection efficiency, as well as safety, leveraging the existing CV technologies. The goal of this project is to compare how two different communications technologies (DSRC and 4G/LTE cellular) are able to support a specific CV application utilizing the California CV Test Bed in Palo Alto; *Project Sponsor: Caltrans; Funding Amount: $199,999.00; Date Completed: 2020-10-31; Principal Investigator: Zhou, Kun*

ADA Van as a Technology Demonstrator for Disabled Travelers – Caltrans DRISI deserves to assume a leading position in transit automation, automated driving, connected automated vehicles (CAV), connected infrastructure and V2X. Presently, DRISI owns the connected infrastructure testbed at El Camino Real in Palo Alto, but does not have ideas how to effectively utilize it and demonstrate the benefits of the connected environment. This must change. Moreover, DRISI is supposed to showcase the emerging technologies and their applications for other Caltrans divisions and for policy makers. What will

enable DRISI to master its role and fulfill its purpose?; *Project Sponsor: Caltrans; Funding Amount: $600.00; Date Completed: 2026-02-28; Principal Investigator: Kurzhanskiy, Alex*

Prepare MMITSS for Deployment in California (Task 4346) – The Multi-Modal Intelligent Traffic Signal System (MMITSS) has been developed under Connected Vehicle Pooled Fund Study (CV PFS) and several Caltrans sponsored research projects. The MMITSS software has been deployed in the California CV Test Bed1 along El Camino Real and is operational since 2018. To facilitate the MMITSS deployment in California, there is a need to document the existing MMITSS software that has been deployed in the California CV Test Bed, to improve MMITSS source code readability via better commenting, and to provide manual/user-guide for developers, management staff, and maintenance staff. There is also a need to develop a Software Over-The-Air (SOTA) update solution for updating the latest MMITSS software from Caltrans Traffic Management Center (TMC) to field intersections; *Project Sponsor: Caltrans; Funding Amount: $175,000.00; Date Completed: 2026-01-01; Principal Investigator: Zhou, Kun*

Automated Vehicle (AV) Testing Data Sharing and Data Analytics. (Task 4152) – During communications with automated vehicle (AV) companies, many of them expressed the willingness to have interactive engagement with the public agencies and share their AV testing data for the purpose of better maintaining the public roadway infrastructures. In this project, we aim to optimize Caltrans planning, operations, and maintenance by using the big data collected from AV sensors, for example inspecting the roadway conditions and identifying the maintenance priorities. In return, this will improve the roadway conditions in preparing for future AV deployment.; *Project Sponsor: Caltrans; Funding Amount: $300,000.00; Date Completed: 2025-06-29; Principal Investigator: Wang, Peggy*

Guidance on RSU placement for future deployment of CAVs – In this project, a sketch-level planning tool will be developed to provide Caltrans Districts guidance on whether to install RSU for CV/CAV applications identified with high priorities; *Project Sponsor: Caltrans; Funding Amount: $300,000.00; Date Completed: 2025-05-31; Principal Investigator: Gan, Qijian*

D-RIDE: Linking Mass Transit and On-demand Transit Trips – The development of Integrated Dynamic Transit Operation (IDTO) and real-time information about the overall transportation systems (both transit and highway networks) has begun to make dynamic transit operation feasible. One of the dynamic operations, Dynamic Ridesharing (D-RIDE), can substantially improve transit service quality by providing faster, more convenient, and cost effective trips to the traveling public. D-RIDE offers travelers to choose micro-transit, ridesharing, or paratransit to connect to/from mass transit. This project is the Phase II+ of the IDTO system research which focuses on the development and evaluation of the D-RIDE application at the Tri Delta Transit service zones. The D-RIDE function enables travelers to submit their connection and ridesharing request to the IDTO Server, which in turn forward the requests to the DRT application at a strategic time point automatically. Then the travelers are able to arrange their successive trip directly with the on-demand service provider in a seamless way. The operation data and the field test demonstrates the benefit of notable time saving for both the travelers and the transit operators; *Project Sponsor: Caltrans; Funding Amount: ; Date Completed: 2022-03-31; Principal Investigator: Meng, Joshua*

Efficient and Consistent Joint Multi-Agent Prediction for Interactive Planning – In this project, we aim to tackle these open challenges and propose a joint multi-agent prediction framework that is computationally efficient and consistent. We also want to demonstrate that it can be used to enable efficient and safe interactive planning in challenging interactive scenarios, by integrating the joint prediction model with state-of-the-art interactive planning algorithms; *Project Sponsor: BDD; Funding Amount: $80,000.00; Date Completed: 2024-05-31; Principal Investigator: Tomizuka, Masayoshi*

Understanding Corner Cases for Vehicle Detection and Tracking – We propose to build a video dataset, using the I-24 MOTION testbed. The testbed is an array of traffic surveillance camera poles in Nashville, TN. The poles operate 24/7, span over 4 miles of highway, and contain 294 ultra-high definition cameras. Interesting clips of video footage will be selected and annotated by human annotators from the camera live feed. By sampling those corner cases, we hope the dataset could facilitate evaluation and improvement of the state-of-the-art models for vehicle detection and tracking; *Project Sponsor: BDD; Funding Amount: $15,000.00; Date Completed: 2024-05-31; Principal Investigator: Bayen, Alexandre*

Computationally Efficient Option-based Monte Carlo Planning for POMDP – The MCTS-based planner is used to search options, which significantly reduce the search space and computational complexity. We want to demonstrate that the proposed method is capable of efficiently solving challenging driving tasks which are impossible to be solved by conventional MCTS-based planning approaches; *Project Sponsor: BDD; Funding Amount: $54,000.00; Date Completed: 2024-05-31; Principal Investigator: Tomizuka, Masayoshi*

Online Automatic Construction and Update of HD Maps with Rich Semantics – In this project, we will further extend our automatic HD map construction method [1] into an end-to-end fashion, enabling online map generation compatible with formats with rich semantics and parameterized representation such as OpenDRIVE.; *Project Sponsor: BDD; Funding Amount: $54,000.00; Date Completed: 2024-05-31; Principal Investigator: Tomizuka, Masayoshi*

Improving OOD Generalization Through Metric-informed Weight-space Augmentation and Architecture Search – This proposal explores novel weight-space augmentations to improve the model's robustness to weight-space perturbations. We propose novel training objectives and ensemble learning methods for improved weight-space robustness by exploiting our strength in Hessian-based loss landscape analysis. We also propose metrics that can be used to measure the global structure of loss landscapes, beyond local Hessian-based methods, and we will use those to improve our training and robustness performance."; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2024-05-31; Principal Investigator: Keutzer, Kurt*

Systematic Quantization on Vision Models for Real-time and Accurate Inference in ADAS/AV – In this project, our goal is to systematically study quantization on various neural architectures and on various applications that are particularly relevant to ADAS/AV. In previous projects, we have developed two Hessian-based quantization frameworks, HAWQ and ZeroQ.; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2024-05-31; Principal Investigator: Keutzer, Kurt*

Collision Indeterminacy Prediction via Stochastic Trajectory Generation – In this project, we propose a stochastic trajectory generation to determine the possible collision between traffic participants by taking into account the uncertainty and variability of the future movements of the ego vehicle and other participants. Stochastic trajectory generation provides a more informative representation of the uncertainty and variability in object movement, as the motion of the object is represented as a probability distribution over possible future states.; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2024-05-31; Principal Investigator: Delle Monache, Maria Laura*

Theoretical and Empirical Investigations of Active Learning and Multi-agent Learning in Autonomous Vehicles – In this proposal, we aim to both empirically and theoretically develop principled and efficient algorithms for active learning and multi-agent learning in Stackelberg game. For active learning, we hope to combine the insights from the new theoretically-motivated online learning algorithms with the

applications in autonomous driving. For Stackelberg game, we hope to propose new policy training framework that incorporates the multi-round interactions in the real-world driving scenario.; *Project Sponsor: BDD; Funding Amount: $15,000.00; Date Completed: 2024-05-31; Principal Investigator: Jiao, Jiantao*

Transportation System Optimization

New Data and Methods for Estimating Regional Truck Movements: This project evaluates how the probe-data analytical platforms could be used to analyze truck movements within Caltrans District 1. This is accomplished by first reviewing existing fixed-location data collection capability and highlighting key gaps related to the ability to monitor truck movements. Following a brief overview of StreetLight's 2021 analytical capabilities, the study then looks at the Sample Trip Count and uncalibrated Index values returned for three weigh-in-motion and twelve Traffic Census stations for each month between December 2019 and October 2021. This is followed by a description of StreetLight's single-factor calibration process, which can be used to convert Index values into volume estimates, and how truck-related calibration data were extracted from the classification counts obtained from weight-in-motion and Traffic Census stations. Key evaluations are then presented. This includes comparisons of uncalibrated StreetLight Index values to observed truck counts to assess data quality and evaluations of impacts of considering alternate calibration data sets and analysis periods. Two test showcases, one featuring an isolated divided highway and another an urban intersection, are also presented to highlight issues with the single-factor calibration process. The study concludes by indicating that probe data analytical platforms such as StreetLight can be used to obtain rough estimates of truck volumes on roadway segments across an area or to analyze routing patterns. The results further indicate that the accuracy of volume estimates heavily depends on the availability of sufficiently large samples of underlying tracking data and the availability of stable and representative month-by-month calibration data over an analysis period across all reference locations. *Project Sponsor: UCB-ITS SB-1 Funding Amount: $80,000 End Date: June 2022 Principal Investigator: Dion, Francois*

After Study for the Richmond San-Rafael Bridge and Sir Francis Drake Pilots (Phase II): Evaluation of impacts associated with the pilot multi-use path that was opened across the upper deck of Richmond-San Rafael bridge in November 2019 and the pilot modifications that were made to the bike path running across the Sir Francis Drake off-ramp overpass during the summer of 2020. Specific elements evaluated include the use of paths by cyclists and pedestrians, impacts on westbound traffic conditions, impacts on incidents and incident responses, and impacts on maintenance activities. These elements are to be used by Caltrans at the end of the project to determine whether the changes should be kept, in whole or in part. This study has been completed. *Project Sponsor: Caltrans Funding Amount: $450,000 End Date: June 2024 Principal Investigator: Dion, Francois*

After Study for the Richmond-San Rafael Bridge (Phase I): Evaluation of impacts associated with the following changes that were made to the Richmond-San Rafael Bridge as part of a pilot project: (1) opening to traffic of the eastbound shoulder lane on the lower deck of the bridge between 2 PM and 7 PM every day (April 2018) and (2) conversion of the westbound shoulder lane on the upper deck of the bridge into a barrier-separated shared bike/pedestrian (November 2019). Specific elements evaluated include traffic compliance with the shoulder lane open/close periods, use of bridge paths by cyclists and pedestrians, impacts on eastbound and westbound traffic conditions, impacts on incidents, incident clearance times, maintenance activities, and quality of life in Marin County areas near the bridge. These elements are to be used by Caltrans to determine whether the changes should be kept, in whole or in

part. This study has been completed. *Project Sponsor: Caltrans Funding Amount: $346,500 End Date: June 2022 Principal Investigator: Dion, Francois*

Digital Mobility Assistant for Disabled Transit Users: PATH researchers will focus on working with the disabled community of Contra Costa County through the center for Independent Living Resources of Solano and Contra Costa Counties (ILRSCC). They will build a knowledge graph (KG) of disabled travelers with their needs, restrictions, preferences, and points of interest (POIs); and mobility services including transit, paratransit and private companies such as Uber WAV with their schedules, coverage areas, cost, etc. As the KG grows, new relationships between existing entities may be discovered. A knowledge update engine will be a distinguishing feature of the system. A review-like function will be the core feature of the KG built on the semi-automatic collection of feedback, reviews and surveys. This will update user preferences. The information contained in the KG will be accessible through an Application Programming Interface (API) by a functional prototype user interface (UI). The goal of this research is to build a working prototype system that would help generate a travel plan for a disabled person using available mobility options that include transit and paratransit but is not limited to those. *Project Sponsor: Caltrans Funding Amount: $300,000 End Date: August 2023 Principal Investigator: Kurzhanskiy, Alex*

Monitoring Post-COVID-19 Transit Operation Recovery and Exploring New Opportunities for Dynamic Transit: Mass transit is in crisis. The recent ridership decline has been seriously exacerbated by COVID-19 and the subsequent shelter-in-place orders. This project provides a better understanding of the impact of COVID-19 and its recovery on transit. In addition, it evaluated the tactics used by different transit agencies to mitigate COVID-19 -19 challenges as well as develop approaches to share key information between agencies. *Project Sponsor: UCB-ITS SB-1 Funding Amount: $50,000 End Date: October 2021 Principal Investigator: Kurzhanskiy, Alex*

Bus Operations of Three San Francisco Bay Area Transit Agencies during the First Year of the COVID-19 Pandemic: From March 2020 through March 2021, researchers monitored three San Francisco Bay Area transit agencies: two large –Alameda-Contra Costa Transit District (AC Transit), Valley Transportation Authority (VTA); and one small –Tri Delta Transit, to assess ridership during the COVID-19 pandemic. They discovered that there was a direct relationship between the socioeconomic status of the population and transit ridership. Higher ridership was observed in low-income areas with a high percentage of Latino, Black and Asian populations who are generally renters, who do not have a car, but have to go to work either because they are essential workers and/ or are undocumented immigrants who cannot afford staying jobless. Conversely, in wealthy areas of the Bay Area, transit activity all but disappeared. *Project Sponsor: UCB-ITS SB-1 Funding Amount: $50,000 End Date: 2021 Principal Investigator: Kurzhanskiy, Alex*

Ramp Metering and High-Occupancy Vehicle (HOV) Lane Degradation Mitigation: The proposed study will expand on the Kimley-Horn study by looking at different California sites with degraded HOV lane performance that have diverse characteristics, analyze the causes of congestion and explain the nexus between ramp metering strategy and improvements in HOV lane performance. The project goal can be succinctly stated as follows: find out which types of ramp metering (e. g. , local, coordinated, on HOV preferential lanes, etc.) can improve the performance of the HOV lanes with various features (full vs limited access, density of on-ramps, bottleneck cause, severity of degradation) and to what extent, which will be quantified. Theoretical analysis will be conducted using simulation in Operations Planning Toolbox (OPT) recently developed by PATH for Caltrans. OPT is an open-source, multi-modal traffic modeling software for quantitative assessment of operational scenarios. It supports the model for managed lanes and various types of ramp metering and different metering rates for the general purpose

(GP) and HOV lanes. If ramp metering does not mitigate the HOV degradation at a certain site, we will analyze why and suggest an alternative to ramp metering. *Project Sponsor: Caltrans Funding Amount: $280,000 End Date: July 2023 Principal Investigator: Kurzhanskiy, Alex*

Working Group to Address APC Problem: Transit ridership data comes from automated passenger count (APC) systems, which are electronic machines that count the number of passengers that board and disembark at every bus stop. Currently, their cost varies between $2. 5K and $10K per bus, but, combined with automatic vehicle location (AVL) systems, aggregation and analysis software, the cost may jump dramatically. APC systems are supposed to generate robust ridership information on a stop-by-stop basis and to enable assessment of bus occupancies on different segments of bus routes. APC data can be used to assess bus utilization, to determine schedule adherence and whether bus routes need more or less running time to get between endpoints. In the mid- and post-COVID environment the real-time APC data can help travelers plan their trips to avoid overcrowded transit. To summarize, accurate APC data are critical for effective transit planning, efficient operation and traveler comfort. PATH is organizing and running a Working Group to address the APC problem. The working group will include transit agencies of the San Francisco Bay Area, municipal and regional representatives and private industry. The group will build on existing research to provide a profile of the APC technology provider market for public transit, with a specific focus on providers for buses and shuttles. Our focus will be placed on companies that provide APC solutions, either stand-alone or within a technology set. We will engage regional transit agencies and operators to better understand adoption barriers and potential points of coordination. We will develop a strategic plan addressing the most likely pathways to improved adoption and development of the data platform. We will profile the feasibility of two different approaches and focus on vehicle retrofit and technology upgrades, and a focus on certain vehicle or service types. We will convene a focus group of transit operators and technology providers to validate these approaches and provide recommendations and options to Caltrans. Finally, we will develop a pilot project or campaign outline that addresses potential next steps. *Project Sponsor: Caltrans Funding Amount: $100,000 End Date: May 2022 Principal Investigator: Kurzhanskiy, Alex*

SMART Mobility Task 6 – Quantify Technology Impact Across Workflow: The SMART Mobility modeling workflow has been developed to evaluate new transportation technologies such as connectivity, automation, sharing, and electrification through multi-level systems analysis that captures the dynamic interactions between technologies. Through integration of multiple models across different levels of fidelity and scale (i.e. , individual vehicles to entire metropolitan areas), the workflow yields insights about the influence of new mobility and vehicle technologies at the system level Argonne and LBNL will validate workflow across multiple tools (RoadRunner, AimSum, POLARIS) into one technology (Task 6). *Project Sponsor: Department of Energy Funding Amount: $123,000 End Date: December 2021 Principal Investigator: Lu, Xiao-Yun*

Data Standardization for Regional Transit and Transit Hubs: The proposed study will provide data tools to multimodal riders, infrastructure stakeholders and transit operators as well. The quantitative and statistical demand data will be offered to recommend capacity designs for potential Mobility Hubs. Eventually, these outcomes will smooth commute trips by offering MaaS trip planning, equitable connection services and demand-driven facilities. *Project Sponsor: College of Engineering Funding Amount: $67,125 End Date: June 2023 Principal Investigator: Meng, Joshua*

Reimagining Sensor Deployment (Task 3942): This project reimagines sensor deployment in the context of a near-term possibility where third-party data is procured to obtain travel times and speed data across the state. In this potential future the role of dedicated roadside detection stations would change. It

would no longer be necessary to target the deployment of detection stations at every half-mile. Therefore, a new paradigm is required to guide the decisions on where detection stations should be placed to provide the most informational value. that could not be possessed by a current, or prospective, Caltrans employee in the Transportation Engineer, Research Data Specialist, or Research Scientist Engineering classifications. Specifically, this task order scope of work cannot be accomplished within the State civil service system due to the specialized nature of this research regarding: (1) alternative data fusion models utilizing new algorithms; (2) information theoretic approaches to data mining; and (3) the creation of new standards or guidelines based on the likely performance of innovative algorithms and approaches that are beyond the scope of current practice. *Project Sponsor: Caltrans Funding Amount: $250,000 End Date: March 2023 Principal Investigator: Patire, Anthony*

Multiple ICM Corridor Management (Task 3706): ICM success depends on understanding and mitigating the impacts of incidents in one corridor upon other interconnected corridors. This project will provide foundational tools to understand large-scale traffic patterns and considerations for the design of future interconnected ICMs. Ultimately, interconnected ICMs should support each other's objectives. Better traffic management decisions will translate to better environmental outcomes and improved livability. *Project Sponsor: Caltrans Funding Amount: $250,000 End Date: September 2021 Principal Investigator: Patire, Anthony*

Cybersecurity of Our Transportation Ecosystem (SB1 Project): Transportation infrastructure is becoming increasingly digitized and connected, as is the world around it. Unfortunately, it continues to be a few steps behind other industries in its implementation of technology. Connectivity is often fragmented, and systems often remain in place with limited updates for decades, and much more dependent on other industries and services. This project, headed by Brian Peterson, investigates and reviews the California transportation system cybersecurity landscape, surveying state, regional, local, and private transportation system elements. This completed report examines trends in cyberattacks and cybersecurity, impacts on transportation, vulnerabilities, and attack vectors including real-world instances of these attacks, and potential steps to address our transportation systems cybersecurity challenges. It explores issues that impact California's ability to address its cybersecurity vulnerabilities, including system oversight, leadership, and management, as well as system and security funding, technology, resources and skills available, and the changing technology landscape of transportation. *Project Sponsor: UCB-ITS SB-1 Funding Amount: $50,000 End Date: December 2022 Principal Investigator: Peterson, Brian*

Modernization of Center-to-Center Data Communication Standards: This document presents a review of the current and future requirements for information exchange between traffic management centers, with emphasis on the changes expected due to the changing nature of transportation and the advances in technology that are becoming prevalent in the transportation ecosystem. The intent of this document is to provide a look at the source of changes required within center-to-center communication and new requirements that will need to be addressed as transportation undergoes significant change due to new transportation modes, technology advances in connected and automated vehicles, advances in infrastructure elements, and other changes that are expected in the future. *Project Sponsor: Caltrans Funding Amount: $300,000 End Date: December 2021 Principal Investigator: Peterson, Brian*

Complete Cities: Bicycle Network Connectivity Evaluation Methodology: Bicycling is one of the most environmentally sustainable, low-cost, and healthy transportation modes available. With 50% of trips made in California being less than 3 miles in distance, bicycling offers enormous potential to combat climate change and improve public health but consistently ranks among the least utilized transportation

modes in the United States. Current industry standard tools for evaluating bicycle level of service are generally microscopic in approach, focusing on individual intersections or segments. There is a need to equip practitioners with a tool and methodology to evaluate an entire bicycle network effectiveness that is generalizable across different locations. This research aims to resolve that by combining mathematical functions from graph theory with knowledge regarding general preferences and behavior of bicyclists into a methodology for measuring bicycle network effectiveness in a study area. The objective is to develop the methodology into a simple and easy-to-use tool to equip planners, engineers, and policymakers with the ability to easily evaluate bicycle networks. *Project Sponsor: Caltrans Funding Amount: $300,000 End Date: December 2023 Principal Investigator: Skabardonis, Alex*

Improved Analysis Methodologies and Strategies for Complete Streets: A complete street is a transportation facility that is planned, designed, operated, and maintained to provide safe mobility for all users including bicyclists, pedestrians, transit vehicles, truckers, and motorists (appropriate to the function and context of the facility). The objectives of this project are 1) development of improved methodology for evaluating the traffic performance of alternative designs for complete streets, and 2) development of signal control strategies to improve the travel experience at signalized intersections for all users. *Project Sponsor: Caltrans Funding Amount: $236,000 End Date: June 2021 Principal Investigator: Skabardonis, Alex*

Better Use of Caltrans Performance Measurement System (PeMS) for Census and Highway Performance Monitoring System (HPMS) Monitoring: This research will apply a multi-step process to verifying the PeMS freeway detector locations and suitability, validating the PeMS traffic volumes (as compared to the published Census volumes). Appropriate PeMS calibration factors will be estimated. This research will result in calibrated PeMS traffic volumes at these 882 locations suitable for use in the Caltrans Census and HPMS programs (and potentially at least some of the 164 additional locations). The cost savings from the research could save on personnel costs over several years. *Project Sponsor: Caltrans Funding Amount: $139,565 End Date: September 2024 Principal Investigator: Skabardonis, Alex*

Research Support For The Freeway Service Patrol (FSP) Program: The Freeway Service Patrol (FSP) is an incident management program implemented by Caltrans, the California Highway Patrol, and local partner agencies to quickly detect and assist disabled vehicles and reduce non-recurring congestion along the freeway during peak commute hours. FSP service is managed by 16 different local government agencies in 25 counties. Field oversight is performed by the California Highway Patrol. Program funding and oversight is provided by Caltrans. The purpose of this research support project is to evaluate the performance of the Caltrans FSP program and create the Annual Statewide and District FSP reports for fiscal years (FY) 2019-20, FY 2020-21 and FY 2021-22. This research support project will produce the Statewide and District Annual FSP Report for Caltrans for FY 2019-20, FY 2020-21 and FY 2021-22 as defined in work tasks of this research support proposal. The Statewide and District Annual Reports will include the results of a program performance evaluation conducted as part of this project. The final reports will be consistent in content and presentation to the Annual FSP Reports produced in past years to enable historical and cross-year comparisons. *Project Sponsor: Caltrans Funding Amount: $669,105 End Date: June 2024 Principal Investigator: Skabardonis, Alex*

Research Support for the SB-1 Funded Extension of the Freeway Service Patrol Program: The purpose of this project is to evaluate the expansion of the Caltrans FSP program funded by SB-1. The tools used and the operational performance measures will significantly contribute to the agencies' efforts to continuously improve the FSP program. *Project Sponsor: Caltrans Funding Amount: $300,000 End Date: December 2022 Principal Investigator: Skabardonis, Alex*

Statistical Support for the Development of D1 Active Transportation Census Program: California Department of Transport (Caltrans) District 1 proposes to develop a statistically robust bicycle and pedestrian census network to elucidate active transportation volumes, travel patterns, and temporal trends. The census network will be paired with a big data platform to allow estimation of volumes on all road/trails across the entire District for the first time. The census network design will be optimized to maximize information utility and minimize cost. The overall network design approach will be scalable to facilitate adoption by other Caltrans districts. A research team at University of California Berkeley will provide statistical design support to design a statistically robust census network that is needed to provide a data-driven basis for engineering decisions related to improvements to the system. The resulting census network design will provide statistically robust and representative data required for engineering and planning decisions going forward. Ultimately, this work will result in safer and more equitable facilities for bicyclists and pedestrians while documenting the progress toward improved safety and mode shift Caltrans is trying to achieve. *Project Sponsor: Caltrans Funding Amount: $288,241 End Date: May 2024 Principal Investigator: Skabardonis, Alex*

Evaluation of Different Coordinated Ramp Metering Systems in Caltrans: This project conducted a detailed study of the operational performance of coordinated ramp metering (CRM) systems recently implemented in three Caltrans districts. *Project Sponsor: Caltrans Funding Amount: $270,940 End Date: November 2020 Principal Investigator: Skabardonis, Alex*

Policy Recommendations for Reducing the Damage of Overweight Trucks on Public Roads by Improving California's Weigh-in-Motion (WIM) System: Many of California's public roads, highways and bridges are in poor condition. Overweight vehicles are responsible for about 60% of road network damage, and studies revealed that the extremely low overweight detection rate is caused by technological gaps of the WIM sensors used in California. *Project Sponsor: UCB-ITS SB-1 Funding Amount: $25,000 End Date: July 2021 Principal Investigator: Zhang, Wei-Bin*

LADOT's ATCMTD in the LA Promise Zone – PATH will provide CV-based Transit Signal Priority (TSP) along the Hollywood DASH route for LADOT's ATCMTD in the Los Angeles Promise Zone project (ATCMTDL 5006(870)). PATH will install MMITSS-LA software on each of the fifty-five (55) signalized intersections along the Hollywood DASH route to communicate with 1) OBUs installed on Hollywood DASH bus fleet via intersection RSUs, 2) field traffic signal controllers, and 3) TPS (Transit Priority System) servers in LADOT Automated Traffic Surveillance and Control (ATSAC) center for TSP operations; *Project Sponsor: USDOT ; Funding Amount: $153,541.00; Date Completed: 2021-00-00; Principal Investigator: Zhou, Kun*

Zero Emissions Mobility

Predictive Data-Driven Vehicle Dynamics and Powertrain Control – A collaboration with Professors Francesco Borrelli and Robert Horowitz from Berkeley's Mechanical Engineering Department, this project aims to develop predictive and data-driven control and planning algorithms which harness connected vehicle technologies, L4 automation and electrification to deliver up to 30% vehicle energy efficiency improvement; *Project Sponsor: DOE ARPA-E NEXTCAR; Funding Amount: $6,804,581.00; Date Completed: 2024-03-21; Principal Investigator: Borrelli, Francesco*

Tools for Demand-Supply Assessment of EV Charging Infrastructure and Strategy Evaluation of Smart Charging – The proposed project studies EV charging infrastructure on three levels: 1) state and regional; 2) community; and 3) individual users. Corresponding to these levels, there are three goals: 1. Build a

dashboard that would monitor the EV infrastructure (EVI) utilization and energy pricing, using data collected from such EVI providers as Blink, EVgo and Tesla. These data can then be aggregated temporally - by hour, day, week, month and year; and spatially - by Census tract; city and county. This enables monitoring the evolution of EVI and its econometrics. 2. Characterize the disadvantaged communities listed in the ANL database by their EVI and its utilization, economic and mobility trends - to identify the category of disadvantaged communities benefiting from the EVI expansion. 3. Develop smart charging strategies for various objectives, such as minimizing cost for the end user, maximizing revenue for the provider, maximizing the number of charged vehicles, flattening the electricity usage peak and their combination, and evaluate them at a UC Berkeley test site with two smart level-2 chargers. Evaluation consists in measuring user response to pricing schemes and fulfillment of the objectives; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $80,000.00; Date Completed: 2023-08-14; Principal Investigator: Kurzhanskiy, Alex*

EEZ Mobility: A Tool for Modeling Equitable Electrification of Zero-emissions Mobility – The distribution of Electric Vehicle ownership and public chargers are unevenly distributed in California with respect to income, race and education-levels. This creates inequitable access to electric mobility and risks technological lockout as EVs scale for low-income communities of color. Additionally, there is greater reliance on public charging stations in these communities due to higher rates of multi-family housing and renters, making access to home charging stations less likely. Income and race also correlate with air quality so these vulnerable communities stand to disproportionately benefit from EV adoption. Currently programs exist in California that fund public chargers and EV incentives in “Disadvantaged Communities” (as defined by CalEnviroScreen), but the identification of these communities do not consider key characteristics like housing type, public transit availability and private charger likelihood. This project proposes constructing a model-based tool that builds on CalEnviroScreen data, and incorporates additional key information to geo-spatially predict economic benefits and health impacts of public charging infrastructure deployment. The tool will guide equitable distribution of funds by maximizing the expected benefits of public charging infrastructure across census tracts; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $80,000.00; Date Completed: 2022-00-00; Principal Investigator: Moura, Scott*

University of California Alliance for Minority Participation (CAMP) and Thermo Fisher Scientific partnership to support undergraduate STEM student-faculty mentored research – At the beginning of each academic year, $2,500 will be allocated to each campus in the Alliance with the purpose of providing the award toward research. CAMP students who are engaged in research during that academic year will submit an omnibus application that is created by the statewide project director that outlines the research and the need for the funds. The remaining $2,500 each year will be used to support statewide activities including the annual research symposium; *Project Sponsor: UC Riverside; Funding Amount: $5,000.00; Date Completed: 2025-06-30; Principal Investigator: Moura, Scott*

Improved Mobility and Energy Savings Through Optimization of Cooperative Driving Automation for Trucks and Passenger Cars in Mixed Traffic Scenarios – As part of this work, LBNL acts as the technical lead working with ITS at the University of California at Berkeley (Subcontractor), on the Energy Efficient Mobility Systems (EEMS) Program that is managed by the Vehicle Technology Office (VTO) in EERE. Recognizing that the existing transportation infrastructure is not adequate to support future needs of the nation, this program is focused on understanding the impact of emerging transportation solutions – such as, Connected and Automated Vehicles and Electric Vehicles (EV) on existing transportation systems, assessing future scenarios that integrate emerging transportation solutions and understand population acceptance, and its impact on mobility patterns and the consequent grid requirements, greenhouse gas

emissions and use of and dependence on fossil fuels.; *Project Sponsor: DOE EERE; Funding Amount: $1,500,000.00; Date Completed: 2025-04-28; Principal Investigator: Lu, Xiao-Yun*

Design of EV Fleets and Charging Infrastructure – With the development of electric vehicles (EVs) and automated vehicles (AV) fleet operator are left wondering how they can adapt and plan for their new generation of vehicles. Some of the challenges include predicting how many EVs a fleet operator would need, where to place charging stations, what size of the battery the vehicles would need. With eCal, Total would like to explore and develop methodology that could help our clients to plan the size of their fleet and the charging infrastructure following a number of optimization parameters. The objective of the optimization of the methods are to minimize CAPEX, OPEX, CO2 emissions and energy consumption; *Project Sponsor: Total S.A.; Funding Amount: $251,410.00; Date Completed: 2024-11-15; Principal Investigator: Moura, Scott*

Seamless & Sustainable Mobility on Demand – This incubation project investigates if a battery swapping station provides a lower total cost of ownership (TCO) and greenhouse gas (GHG) emissions relative to a mega-charging station, for long-haul trucks. It also provides models to optimally plan and operate a battery swapping station. We formulate a mathematical optimization model, solve it, and analyze the results via sensitivity analysis, comparative analysis, progressive feature additions, and case studies; *Project Sponsor: Total S.A.; Funding Amount: $132,258.00; Date Completed: 2024-11-15; Principal Investigator: Moura, Scott*

Connected and Learning Based Optimal Freight Management for Efficiency (DOE VTO) – The project aims to demonstrate a ≥20% fleet level W2W CO2 reduction (per unit of load-distance) over a baseline fleet through optimal adoption of advanced powertrain technologies, connectivity features such as V2I, V2V, V2X and automation such as Partial (L1/L2), ADS (L3+) and optimal operation using connected and learning fleet management algorithms; *Project Sponsor: DOE VTO; Funding Amount: $300,001.00; Date Completed: 2023-12-31; Principal Investigator: Moura, Scott*

Optimal Energy Management of Solar Communities – This 4th-5th year proposed research project focuses on (i) experimental validation of SOx estimation algorithms, (ii) SOC estimation in lithium iron phosphate (LFP) cells, (iii) state-of-energy (SOE) estimation, and (iv) SOC management during frequency regulation; *Project Sponsor: Total Solar International; Funding Amount: $269,400.00; Date Completed: 2024-10-31; Principal Investigator: Moura, Scott*

Smart LeaRning Research Pilot for EV Charging (SlrpEV)-Year 4 – Future sustainable transportation systems will be automated, connected, and electrified. This transition requires completely new paradigms for smart infrastructure built upon data, control, and optimization. In this talk, we highlight SlrpEV (Smart LeaRning Research Pilot for Electric Vehicles) – a novel cyber-physical & human system research platform. SlrpEV seeks to resolve critical obstacles for public & workplace EV charging stations via novel pricing and power scheduling that learns and adapts to user preferences to minimize costs, emissions, and increase accessibility. We close with broad perspectives on building a smart transportation and energy infrastructure that advances both sustainability and equity; *Project Sponsor: Total Solar International ; Funding Amount: $203,966.00; Date Completed: 2023-03-31; Principal Investigator: Moura, Scott*

SlrpEV (Smart Learning Research Pilot for Electric Vehicles) Year 5 – The fifth year of SlrpEV is focused on supporting three main tasks: 1) The objective is to extend SlrpEV-Sim with virtual distributed energy resources (DERs) – such as onsite energy storage, solar generation, and building load consumption data

at nearby locations on/off campus.; 2) Provide detailed data-driven insights into SlrpEV usage; 3) Demonstrate station-level price & power optimization; *Project Sponsor: Total Solar International ; Funding Amount: $110,000.00; Date Completed: 2024-05-14; Principal Investigator: Moura, Scott*

SBIR Phase II: Intelligent Planning and Control Software for EV Charging Infrastructure – The overall goal of the STTR project (including phase 1 and 2) is to develop, build and commercialize an intelligent planning and control software for EV charging infrastructure for transit buses, commercial fleets and private cars. The proposed software will have two applications: planning and operational control. The planning module is for use by planners, consultants, solution architects, and designers to optimize the capacity of the Vehicle battery and EV charging infrastructure that will minimize investments and operational costs. The operational controller will help the facilities to manage the operation of the charging infrastructure in real time to minimize energy costs while preventing any adverse impact on the electrical infrastructure; *Project Sponsor: National Science Foundation; Funding Amount: $104,941.00; Date Completed: 2022-04-30; Principal Investigator: Moura, Scott*

Energy efficient operation of hydrogen powered vessels (HyEff) – The project Energy efficient operation of hydrogen powered vessels (HyEFF) will perform research to facilitate widespread, sustainable, and safe use of hydrogen powered vessels with energy efficient operation. In this project we will further develop a system, based on radar images, for forecasting wave and vessel motions in real time 4-8 minutes in advance. This will set the stage for developing a power management system that minimizes the fuel consumption and extend the lifetime of the fuel cells and batteries of the ship power plant. We will also develop novel measurement technology for characterizing degradation and health of fuel cells, and combine measurements with models for system monitoring and degradation characterization; *Project Sponsor: The Research Council of Norway; Funding Amount: $143,779.00; Date Completed: 2025-06-20; Principal Investigator: Moura, Scott*

CAREER: Estimation and Control of Electrochemical-Thermal Battery Models: Theory and Experiments – The PI's long-term research goal is to enable high-performance energy systems through advancements in control and estimation. In pursuit of this goal, the research objective of this CAREER proposal is to advance knowledge on electrochemical-thermal model-based battery management systems. The PI's long-term educational goal is to inspire and educate a new generation of energy and control engineering leaders. In pursuit of this goal, the educational objective of this CAREER proposal is to build a pipeline of experiential educational activities for broadening participation in energy and controls science; *Project Sponsor: National Science Foundation; Funding Amount: $531,177.00; Date Completed: 2024-02-29; Principal Investigator: Moura, Scott*

State-of-Charge/State-of-Health Estimation in Battery Packs with Heterogeneous Cells (SAFT) – Year 2 Supplement and Extension – This research addresses the challenges of battery management for battery packs with thousands of heterogeneous cells. The research outcomes will provide Saft with advanced methods for state-of-X estimation, without requiring added sensing or large-scale computing; *Project Sponsor: Total Energies E&P Research Technology USA, LLC; Funding Amount: $144,925.00; Date Completed: 2024-10-31; Principal Investigator: Moura, Scott*

SAFT Year 3 Supplement: State-of-X Estimation in Battery Packs with Heterogeneous Cells – This 3rd year proposed research project continues to explore, design and evaluate state-of-charge (SOC), state-of-health (SOH), state-of-power (SOP) and remaining useful life (RUL) estimation in battery packs, where the cells are heterogeneous due to variations in health, temperature, and/or charge levels. We focus on lithium iron phosphate cells (LFP), which are appealing for their low cost, high safety and

lifetime, but particularly challenging for estimation.; *Project Sponsor: Total Solar International ; Funding Amount: $149,743.00; Date Completed: 2024-10-31; Principal Investigator: Moura, Scott*

Drivers' Responses to Eco-driving Applications: Effects on Fuel Consumption and Driving Safety – Eco-driving applications are designed to change a person's driving behavior by providing real-time, vehicle-specific information and advice such as to accelerate slowly and to reduce speed (to optimize vehicle speed, reduce fuel consumption, and reduce emissions). It is not known how effective real time information will be under dynamic traffic conditions. This project will investigate drivers' responses when using ecodriving applications, the effects on fuel savings and emission reduction, and the associated safety impacts through a simulated driving experiment involving a local roadway with signalized intersections and freeway stop-and-go traffic; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $70,254.00; Date Completed: 2021-08-00; Principal Investigator: Wang, Peggy*

Digital Transportation Infrastructure (AI)

Tracking people and objects in 3D: We propose extending our work on tracking humans in 3D to also track objects via spatial-temporal 3D reconstruction. The problem is finding the 3D shape, pose, location, and appearance of multiple people and objects, and track changes over time in an input video. Objects here could include cars, bicycles etc. *Project Sponsor: BDD Funding Amount: $90,000 End Date: 2022 Principal Investigator: Malik, Jitendra*

Erroneous HOV Degradation: The proposed research explores the application of data science to improve the accuracy of highway performance measures, specifically measurement of HOV lanes. The main goal is to develop automated means to identify configuration errors associated with loop measurement of HOV lanes - leveraging the latest research in data science. *Project Sponsor: Caltrans Funding Amount: $150,000 End Date: June 2021 Principal Investigator: Patire, Anthony*

Hybrid Data Implementation: Final Report for Task (3643): This report proposes a methodology for using third-party data to improve Caltrans performance reporting, investigates the advantages and opportunities that come with using this data, and provides a roadmap for Caltrans to move forward with a pilot study. *Project Sponsor: Caltrans Funding Amount: $249,999 End Date: November 2020 Principal Investigator: Patire, Anthony*

Design Automation of Out-of-Distribution Image Data Detectors: Out-of-distribution (OOD) detection is an important topic in computer vision research. Despite the success of prior research in multi-class tasks, the performance of existing OOD detection methods on multi-label tasks is unsatisfactory. In our preliminary experiments, Machine Learning (ML)-based methods have shown much promise for multi-label classification tasks. However, the potential of ML-based methods has been downplayed in prior literature due to the lack of model selection, which is difficult because the OOD images are unknown. To resolve this challenge, we propose to generate OOD data with in-distribution data. Our overall research focus is on designing an automated model selection algorithm using generated OOD data that finds an optimal ML-based OOD detection model and corresponding hyperparameters to achieve robustness against OOD inputs, with a particular focus on autonomous driving applications. *Project Sponsor: BDD Funding Amount: $100,000 End Date: 2021 Principal Investigator: Sangiovanni-Vincentelli, Alberto*

Bridging Simulation and Real Data with Dynamic SCENIC Programs: Sensor realism is one of the most fundamental challenges for the practical use of simulation in autonomous vehicle development and testing. There is a pressing need for techniques to efficiently validate simulation data and results against real-world datasets and testing. In this proposed research, we will develop a novel data-driven approach to automatically validate simulation results against real time-series data. We plan to develop an approach to query a set of labeled, real-world videos of any sensor type (e. g. 2D RGB, 3D LiDAR point cloud, and depth-camera) with a program modeling an autonomous driving scenario in the SCENIC programming language. Through this approach, we plan to bridge the gap between simulated, synthetic, corner-case data and real-world time-series datasets. *Project Sponsor: BDD Funding Amount: $100,000 End Date: 2021 Principal Investigator: Seshia, Sanjit A.*

Automatic Inference of Lane Topology and Connecting Geometry for Scene Understanding, High-Definition Map Construction and Representation: Autonomous vehicles need to understand the driving scenes with semantics such as drivable areas, lanes and intersections. For vehicles to navigate in a complicated urban environment, it is also important to understand the lane relationships. More specifically, it is critical for an autonomous vehicle to know lane connection topologies and geometries on the roads or in the intersections. In this project, we aim at automatically extracting lane relationships from onboard sensors such as LiDAR and cameras and propose novel representation of the implicit connection rules obtained via human prior and motion data. *Project Sponsor: BDD Funding Amount: $100,000 End Date: 2021 Principal Investigator: Tomizuka, Masayoshi*

Data Efficiency for Point Cloud Perception Model: Lidar is a standard sensor for current generations of robotaxis. The preference for Lidar is due to its accuracy in depth estimation and the completeness of its capture of spatial structure. We propose to design the training strategy customized to the point cloud processing model to achieve closed full-supervised performance with the minimum amount of annotated data. Different from the previous work that attempts to save the annotation via unsupervised domain-adaptation, we propose to acquire the data efficiency via self-supervised and semi-supervised training strategies which has been demonstrated to be reliable on the 2D image domain. Applying these strategies Lidar will be novel and valuable to both industry and academia. *Project Sponsor: BDD Funding Amount: $60,000 End Date: 2021 Principal Investigator: Tomizuka, Masayoshi*

Theoretical and Empirical Investigations of the Trade-offs between Open-loop and Closed-loop Planning: In this project, we aim to both empirically and theoretically analyze the differences between open- and closed-loop planning, which will both illuminate the failure modes of existing planning approaches, as well as inform the development of new theoretically-motivated planning algorithms that balance efficiency and optimality. *Project Sponsor: BDD Funding Amount: $90,000 End Date: Principal Investigator: Wu, Tianhao*

Hyperbolic Embedding for Natural Visual Scene Recognition: Visual scene recognition is fundamentally hierarchical, whether in terms of low-level visual structures or high-level semantic concepts. Most deep learning methods develop a visual representation in Euclidean space, which falls short of capturing such hierarchical structures, since a tree cannot be isometrically embedded into the Euclidean space. The hyperbolic space is a continuous analog of a tree structure, and it has been used in natural language processing to encode the semantic hierarchy of WordNet. However, it is unclear how to extract a visual hierarchy in a data-driven fashion, how to exploit the hyperbolic embedding for various visual tasks, and whether it would matter much at all in practice. We propose to leverage our expertise on representation learning for image classification, open long-tailed recognition, and lifelong learning, to answer these questions. Our preliminary results show an easy and significant performance gain in natural visual scene

recognition with the hyperbolic embedding. *Project Sponsor: BDD Funding Amount: $100,000 End Date: 2021 Principal Investigator: Yu, Stella*

Representation Learning for Person Segmentation and Tracking: To understand human activities and behavior patterns from videos, we need to extract a visual representation that captures information relevant for individual persons in a crowd, ideally from naturally captured data with minimal annotations. We propose to leverage our expertise on representation learning for image classification, open long-tailed recognition, object detection, semantic and instance segmentation, and extend it to representation learning of persons from videos, with partial or no human annotations at all on the video frames, for the sake of accurately segmenting and tracking individual persons over time, at the same time facilitating the discovery of behavior patterns. Our goal is to infer “Who is doing what to the store?" more accurately, so that events such as whether an item is moved or taken away and by whom etc. can be analyzed. *Project Sponsor: BDD Funding Amount: $100,000 End Date: 2021 Principal Investigator: Yu, Stella*

Measuring Prediction Trustworthiness and Safety Through Neural Network Loss Landscape Analysis: Deep neural networks are increasingly being deployed in safety critical components, and quantifying their trustworthiness and safety is an on-going challenge. In this proposal, we identify several inefficiencies of prior metrics used to quantify model robustness, with a focus on analyzing safety through loss landscape of the model. We plan to perform a multi-faceted study and pursue the following research thrusts: 1) Study “global” structural properties of loss landscapes instead of local properties; 2) Study generalization metrics that can be calculated without accessing any training or test data; and (3) Develop metrics that can characterize the quality of learning models directly, instead of the generalization gap (test loss subtracted by training loss) often studied in the literature. Furthermore, we also plan to study how these safety metrics, calculated from loss landscapes, can improve model robustness, especially from the following two aspects: 1) Use the loss landscape metrics to robustly quantify generalization when various environmental factors change and/or the data/model is adversely perturbed; and 2) Couple this metric in a Neural Architecture Search framework to adapt the model architecture and make it more robust. *Project Sponsor: BDD Funding Amount: $90,000 End Date: 2022 Principal Investigator: Mahoney, Michael*

Cross-Domain Self-Supervised Learning for Adaptation and Generalization: Most machine learning algorithms have achieved remarkable performance in various autonomous driving applications. Despite high accuracy, deep neural networks trained on specific datasets often fail to generalize to new domains owing to the domain shift problem. In our previous works, we proposed cross-domain self-supervised learning methods and demonstrated their effectiveness on few-shot unsupervised domain adaptation and multi-source few-shot domain adaptation. With cross-domain SSL, the performance boost on domain adaptation is significant. In this project, we aim to develop new cross-domain SSL methods for more complex perception tasks, e. g. object detection and semantic segmentation. We plan to perform cross-domain SSL by finding the region-level relationships between dense features. In addition, we plan to further develop better methods by finding the causal structures and low-dimensional structures under the data generation process. After performing cross-domain self-supervised learning for object detection and semantic segmentation, we propose to leverage the learned representations and train models to achieve better domain adaptation / generalization properties. *Project Sponsor: BDD Funding Amount: $45,000 End Date: 2022 Principal Investigator: Sangiovanni-Vincentelli, Alberto*

3D Object Detection with Temporal LiDAR data for Autonomous Driving: A crucial task in Autonomous Vehicle applications is the ability to accurately detect and infer details about the surrounding objects

accurately, and in a timely fashion. Among existing sensors used for 3D object detection, LiDAR results in highest distance accuracy, and works under low light conditions such as nighttime. In this work, we intend to use these two ideas to perform joint, self-supervised moving object segmentation and scene flow estimation by developing novel loss functions that enforce consistency between the scene flow and object segmentation predictions. We speculate that jointly training the two networks allows each of them to perform better on their respective tasks. We use KTTI dataset to demonstrate the performance of our results. We plan to leverage over $200,000 cloud computing credit with AWS and Azure to run our training algorithms. *Project Sponsor: BDD Funding Amount: $100,000 End Date: 2021 Principal Investigator: Zakhor, Avideh*

Multi-Modal Self-Supervised Pre-training for Label-Efficient 3D Perception: Multi-modal self-supervised pretraining (e. g. , CLIP [3]) opens up a new direction for us. CLIP shows superior zero-shot performance with much less image-text paired data (e. g. , 12x fewer) than pretraining on the single modality. To this end, we propose a calibration-agnostic multi-modal self-supervised pre-training method to achieve label-efficient 3D perception (e. g. , using 1% labels to achieve the performance comparable to using 100% labels). *Project Sponsor: BDD Funding Amount: $45,000 End Date: Principal Investigator: Zhan. Wei*

Assessment of Infrastructure Needs for Deployment of Connected Vehicle Technologies: This white paper will assess the current state of development of CV technologies, particularly those that involve cooperation with the infrastructure, and will analyze the gaps, needs and requirements of CV technologies and applications from the perspectives of system level safety, efficiency, reliability and resilience. The study will also provide predictions on the timing of commercially available CV technology and provide recommendations for California infrastructure owners and operators regarding necessary preparation efforts. *Project Sponsor: UCB-ITS SB-1 Funding Amount: $25,000 End Date: May 2021 Principal Investigator: Zhang, Wei-Bin*

Information Display Board for Corridor Management in California – California Department of Transportation (Caltrans) has proposed to display graphical messages and text messages on Information Display Board (IDB) along Interstate 80 between the Carquinez Bridge and the Bay Bridge. The purpose is to convey additional traveler information, such as estimated travel time to popular destinations and expected delays, in order to enhance drivers' knowledge of the downstream traffic conditions and to provide information about alternative routes and alternative transportation modes. California PATH, on behalf of Caltrans, conducted an independent research project using human-factors approaches, aiming at generating a recommendation report in order to be used by Caltrans to obtain approval from FHWA. Besides, this project also aimed to conduct fundamental research for the evaluation of IDBs, with knowledge and insights that can be potentially generalized on other corridors in California and across the country; *Project Sponsor: Caltrans; Funding Amount: $449,958.00; Date Completed: 2020-06-30; Principal Investigator: Chan, Ching-Yao*

Exploring the Operational and Equity Benefits of a Pre-Pay Dynamic Tolling System – While transportation funding can be collected in a variety of direct (e.g., fares, tolls, and gas taxes) or indirect (e.g., property and sales tax) ways, dynamic demand responsive pricing not only collects revenue but incentivizes travelers to avoid peak-demand periods, thus utilizing infrastructure capacity more efficiently. Unfortunately, the demand response to price changes, called price elasticity of demand, is generally greater for longer-term travel planning (e.g., air and rail travel) than it is for more atomized short-term planning (e.g., highway tolls and transit fares). While this is due to a plethora of factors (e.g.,

time flexibility, housing choice, automobile investment, etc.), a critical factor is that travelers simply lack sufficient information for future travel planning. For example, airline prices at different times can easily be compared, but a highway driver cannot accurately predict congestion nor congestion pricing. For this reason, such price changes have little effect on demand. This leaves any congestion abatement up to inefficient trial and error, and anecdotal speculation by travelers. Moreover, dynamic pricing is politically unsavory due to price uncertainty and collateral equity concerns. This article seeks to help remedy these concerns by proposing a simple "futures" market mechanism that can augment existing fare/toll collection technologies, providing travelers with sufficient pricing information and purchasing options to preplan their travel and avoid excessive prices. Users can optionally pre-pay their future fares/tolls to lock in a lower price for expected trips, thus encouraging good travel planning and efficient infrastructure utilization, while reducing price uncertainty. This research explores a potential remedy through a futures market-based toll pricing mechanism. The proposed concept is simple: travelers can lock in their toll price by pre-paying for future tolls, with the future price increasing as more travelers book an overlapping time slot. This encourages travelers to avoid traveling during those peak periods as the price increases towards capacity, or to purchase trips in advance while the price remains low or discounted; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $80,000.00; Date Completed: 2022-09-00; Principal Investigator: Skabardonis, Alex*

Agent Behavior Understanding in Crowds – Predicting Future Trajectories and Activities – The objective of this proposal is to provide an end-to-end, multi-task, machine learning system utilizing rich visual features about human behavioral information and their interaction with surroundings. A machine-learning network will be trained to predict future activities from its location using large-scale camera data of human interactions. Previous work on crowd-behavior analysis, future forecasting, activity recognition, and unsupervised embedding of camera images will be leveraged; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $50,794.00; Date Completed: 2021-06-00; Principal Investigator: Chan, Ching-Yao*

CPS: TTP Option: Synergy: Traffic Operating System for Smart Cities – This project will advance research in several areas of Technology for and Engineering of Cyber-Physical System (CPS). We will develop new design, analysis, and verification tools for TOS, which will embody the scientific principles of CPS, rely on extensive use of heterogeneous sensors, large-scale data collection and processing, and will actively control the dynamics of a transportation network. We will field-test traffic estimation and prediction models using sensor measurement and signal timing data from the cities of Pasadena, Sierra Madre and Arcadia in Southern California. Field test of the combined vehicle-level and traffic-flow-level control, using actual connected vehicles and vehicle-to-infrastructure (V2I) communication with a signalized intersection, will be conducted in the transition to practice (TTP) component of our project. The synergistic combination of research activities will yield novel scientific, technological and practical engineering implementation results in the design, state estimation, forecasting and control of CPS that involve transportation flows on networks. This is an NSF project, total grant is ??; *Project Sponsor: Caltrans; Funding Amount: ; Date Completed: 2021-06-00; Principal Investigator: Kurzhanskiy, Alex*

Uncertainty-Aware Reinforcement Learning for Interaction-Intensive Driving Task – In daily driving, drivers often need to deal with various types of uncertainties, among which is the critical factor of the intrinsic uncertainty of road users' behaviors. In this project, we propose to develop uncertainty-aware decision-making algorithms for interaction intensive driving tasks, e.g., performing maneuvers in dense

traffic and negotiating with surrounding vehicles with highly variant behaviors. We will exploit and improve current methods to address aleatoric (road user behavior) and epistemic (knowledge gaps) uncertainties; *Project Sponsor: UCB-ITS SB-1; Funding Amount: $46,000.00; Date Completed: 2021-06-00; Principal Investigator: Chan, Ching-Yao*

A Level of service model for separated bicycle lanes: Preliminary Calibration using rank-ordered survey estimation – This paper presents several proposed revisions to the existing Highway Capacity Manuals methodology for bicycle LOS. The proposed revisions include methodologies to account for separated bicycle lane buffers along links, estimated bicycle delay from right-turning motorists, estimated bicycle delay when performing one- and two-stage left turns, and the motorized traffic speed exposure of bicycles at intersections. The proposed revisions are largely comprised existing methodologies (e.g., pedestrian delay at two-way stop-controlled intersections) and classical analytical approaches that fall seamlessly into the existing Highway Capacity Manual's formulaic approach; *Date Completed: 2021-01-00; Principal Investigator: Fournier, Nicholas*

Contra Costa Transportation Authority's (CCTA) for the USDOT Automated Driving System Demonstration – Together, the U.S. Department of Transportation and the Contra Costa Transportation Authority (CCTA) are sponsoring an ongoing project, "Contra Costa Transportation Authority's (CCTA) for the USDOT Automated Driving System Demonstration". Three proposed demonstration projects within this project will gather data and use it to develop and evaluate safety performance measures. The data will be managed by CCTA and stored in a cloud-based platform where authorized team partners can access, read, download, and/or process the data. The primary goals for these demonstrations are to increase transit accessibility for the elderly community using shared AVs, provide on-demand and wheelchair accessible AV shuttle service to people without access to transportation, and to prepare the corridor for future CAVs. To accommodate both CAV technology and implementation of innovative operational strategies, new and upgraded vehicle-to-vehicle infrastructure and vehicle-to-vehicle communications will be installed; *Project Sponsor: Contra Costa Transportation Authority; Funding Amount: $850,000.00; Date Completed: 2025-06-30; Principal Investigator: Chan, Ching-Yao*

Analysis and Synthesis of Road Vehicle Conflicts using Vehicle Trajectory Data – Progress in traffic safety, in both the current system and the increasingly automated future, depends on shifting toward a more proactive approach in which hazardous conditions are foreseen and mitigated prior to the occurrence of crashes. In the context of vehicle-to-vehicle collisions, the precursor condition is often referred to as a "conflict." It is therefore of interest to analyze the incidence of vehicle conflicts. Given that conflicts are relatively rare, a research challenge is to maximally exploit the limited trajectory data available to analyze and predict conflict occurrence. We propose to develop the data-driven real-time risk predictive framework, using real-world driving data and advanced machine learning techniques, to continuously monitor and identify potential risks of vehicle-to-vehicle conflicts. This framework incorporates unsupervised learning for conflict identification, deep generative models to augment the conflict samples, sequential learners to make predictions, and data streaming pipeline for real-time deployment. This basic research can mature into capabilities with a variety of use cases for both conventional and automated vehicles; *Project Sponsor: BDD; Funding Amount: $90,000.00; Date Completed: 2023-05-31; Principal Investigator: Hansen, Mark*

Driver Drowsiness Analysis Based on Multiple Facial Features – Operating a motor vehicle while fatigued or sleepy is commonly referred to as "drowsy driving." Drowsiness makes drivers less attentive,

slows reaction time, affects a driver's ability to make decisions. A driver might not even know when he or she is fatigued because signs of fatigue are hard to identify. Some people may also experience micro-sleep – short, involuntary periods of inattention. In the 4 or 5 seconds a driver experiences micro-sleep, at highway speed, the vehicle will travel the length of a football field. Drowsy driving is a serious traffic problem in the United States. Our proposed work is based on behavioral parameters, which is a way to detect drowsiness based on a non-invasive method. Human drowsiness is measured by behavior parameters such as blinking, head position, facial expression, yawning, and eye-closing rate. We hope that this work can find innovative definitions via a combination of facial features, and the results of this research can advance the understanding of drowsiness. Ultimately, we hope it will lead to preventive measures to improve traffic safety; *Project Sponsor: BDD; Funding Amount: $15,300.00; Date Completed: 2023-05-31; Principal Investigator: Chan, Ching-Yao*

Intention-aware Pedestrian Motion Modeling and Prediction – Pedestrian motion modeling is an active research topic and useful in many applications, such as surveillance systems, pedestrian tracking, vehicle motion planning, city planning, urban design, evacuation planning, etc. Recently, researchers have proposed deep-learning-based models, which are trained by pedestrian trajectory datasets. By taking advantage of expressivity of the deep neural networks, these models are good at capturing the latent pedestrian dynamics and approximating the pedestrian motion. We propose a model that combines the advantages of interpretability in traditional models as well as the generalizability of the deep learning model, to predict agent trajectories by considering the historic trajectories, social interactions, and physical environment; *Project Sponsor: BDD; Funding Amount: $90,000.00; Date Completed: 2023-05-31; Principal Investigator: Chan, Ching-Yao*

Safety Evaluation of Automated Driving Systems – This project is a review of additional literature to explore the fundamental issues for the safety evaluation of ADS. In the review of methodologies for safety evaluation, we focus on the scenario-based method and dive further into how a framework can be constructed. For the next phase of this project, we focus on the scenario-based method since (1) we can customize test scenarios and avoid wasting time on simple and repeated scenarios, (2) it allows us to evaluate rare and extreme scenarios. After identifying the risk factors, each of the risk factors are going to derive critical scenarios and test scenarios. At the end, the test scenarios can be tested on test platforms such as virtual test platforms, track-test platforms and real-world test platforms. The test platforms need to make sure its result is repeatable and traceable; *Project Sponsor: BDD; Funding Amount: $90,000.00; Date Completed: 2023-05-31; Principal Investigator: Chan, Ching-Yao*

In-Car AI Assistant: Efficient End-to-End Conversational AI System – Recent advances in Deep Neural Network (DNN) based conversational AI systems have significantly improved smart assistants. These systems have created a seamless user- experience, and are now widely adopted in mobile phones and smart speakers. These successes motivate the application of dialogue systems to more safety-critical use cases such as cars, where it is crucial that the driver be able to stay focused on the road and not have to deal with the complex infotainment interfaces. However, there are many barriers in deploying an accurate AI Assistant in cars. First, the current technology deployed by smart speakers requires constant cloud connection. This is due to the high computational costs required to process a user's audio signal, understand a user's intent or command, manage dialogue state, and generate human-like speech. Another important challenge is the large model sizes in the current state- of-the-art speech and language processing tasks, which use the transformer models. These DNNs have a prohibitive memory for them to

be deployed within the memory budget of the edge. To address these, we plan to pursue a multi-faceted approach to design an end-to-end system that can be efficiently deployed at the edge, within the hardware budget of typical autonomous driving cars. In particular, we will pursue the following directions. First, we will design and train an end-to-end model that receives user's acoustic data as input, and performs an integrated Automatic Speech Recognition (ASR), Natural Language Understanding (NLU), Dialogue State Management (DM), Natural Language Generation (NLG) and Text-to-Speech (TTS) in one-pass. This can lead to orders of magnitude reduction in model footprint and improved latency, as compared to conventional modular- based solutions. We will further optimize the previous prototype, through a differential Neural Architecture followed by compres- sion (quantization, hierarchical pruning, and distillation). If it is of interest to sponsors, we can also investigate co-design focused on a particular processor target; *Project Sponsor: BDD; Funding Amount: $59,400.00; Date Completed: 2022-05-31; Principal Investigator: Kuetzer, Kurt*

Vehicle Dynamic Estimation based on Image Sensor & Radar Fusion – This project is aimed at the development of an intelligent vehicle dynamics estimation model based on a camera-radar fusion system. Our model uses a deep learning approach for feature extraction and integration of multiple data sources. We expect the methodology developed in this project can be extended to other vehicle applications. As an example, temperature, pressure, rotational speed, casing vibration, control actuator positions, flow rate, clearance between stationary and rotating parts, and lubrication oil quality can be correlated with engine health. However, it takes a great deal of time and energy to perform simulation calculations using inverted mathematics models. Using a variety of human characteristics can determine the driver's excitement, fatigue, and other parameters. The same model design concept can establish correlations between various signals. The general goal of this project is to create a deep learning model with a methodology suitable for big data with multi-sensor features; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Chan, Ching-Yao*

Efficient Deep Learning for ADAS/AV Through Systematic Pruning and Quantization – An important barrier in the deployment of deep neural networks is latency, which is critical for autonomous driving tasks. High latency can lead to delayed recognition of an object or a pedestrian in front of the car, making it challenging to take the appropriate maneuver in time. For this reason, practitioners have been forced to use shallow networks with non-ideal accuracy to avoid this latency problem. We plan to address this challenge by developing a systematic multi-faceted approach for end-to-end efficient NN design and deployment by pursuing the following thrusts: (i) developing a fast coupled quantization and pruning framework that allows the practitioner to obtain optimal trade-offs between accuracy, and speed for a given latency constraint; (ii) developing a quantization and pruning aware Neural Architecture Search co-designed for a target hardware platform for autonomous driving with limited power budget; and (iii) focusing on object detection and segmentation applications with 4K video stream. The outcome of this work will be an open-source framework that will automatically find an efficient NN architecture for the application-specific constraints of accuracy, latency, model size, and power consumption; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Gholami, Amir*

Embedded In-Car AI Assistant: Efficient End-to-End Speech Recognition and Natural Language Understanding for Command Recognition at the Edge – Recent advances in Deep Neural Network (DNN) based Natural Language Understanding (NLU) have significantly improved smart assistants. These

systems have created a seamless user experience, which is now widely adopted in mobile phones and smart speakers. These successes motivate the application of NLU to more safety-critical use cases such as cars, where it is crucial that the driver be able to stay focused on the road and not have to deal with the complex infotainment interfaces. However, there are many barriers in deploying an accurate AI Assistant in cars. First, the current technology deployed by smart speakers requires constant cloud connection. This is due to the high computational costs required to process a user's audio signal, and subsequent NLU to find the intention or command of the user. Another important challenge is the large model sizes in the current state-of-the-art NLU phase, which uses the transformer models. These DNNs have a prohibitive memory for them to be deployed within the memory budget of the edge. To address these, we plan to pursue a multi-faceted approach to design an end-to-end system that can be efficiently deployed at the edge, within the hardware budget of typical autonomous driving cars. In particular, we will pursue the following directions. First, we will design and train an end-to-end model that receives user's acoustic data as input, and performs an integrated automatic speech recognition and NLU in one-pass. This can lead to orders of magnitude reduction in model footprint and improved latency, as compared to conventional two-pass solutions. This is due to the fact that the domain-specific commands used in the car have a much smaller range as compared to the complex intents that can be present in spoken language. Second, we will further optimize the previous prototype, through a differential Neural Architecture Search followed by compression (quantization, hierarchical pruning, and distillation). We will also apply domain-specific biasing by taking into account the context of the user (such as contact list names to increase the detection accuracy). Furthermore, we will co-design the solution for a target edge hardware used for autonomous driving. We will also perform direct deployment of the model and provide an end-to-end solution that can be used within the constraints of the edge (i.e. latency, power, and memory footprint). This project builds upon our recent works on efficient NLU models; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Gholami, Amir*

Few-Shot Imitation and Embodiment Transfer – In this research for few-shot imitation and embodiment transfer we will investigate advanced attention-based neural architectures, which could allow the agent to generalize to conditions and tasks unseen in the training data. Also, we will leverage unsupervised representation learning like contrastive learning and cycle-consistency to extract the few-shot signal and invariant features from demonstrations with domain gaps. We hypothesize that this new framework will enable agents to solve unstructured real-world challenges using a few demonstrations via imitation learning; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Abbeel, Pieter*

Hessian Aware Neural Cleansing: Searching for Optimal Trade-offs between Adversarial Robustness, Accuracy, and Speed – One of the on-going challenges with Neural Networks has been their vulnerability to adversarial attacks. Despite significant efforts in developing defense strategies, this challenge has remained unresolved, and all of the proposed defenses have been broken by very simple attacks. However, in the past year, there have been several important works that have provided intriguing new insights about the different sources of this vulnerability. These can be categorized into non-robust features in the training data, as well as non-robust components of the Neural Network model itself. In this proposal, we aim to build upon these works and develop a Neural Cleansing framework for designing robust and accurate models. To achieve this, we will first investigate the decision ``boundary thickness'' and its correlation to NN architecture, as well as different types of non-robust input training data. Then,

based on this, we will design a novel Hessian Aware Neural Cleansing approach, to systematically prune and replace non-robust components of the NN model. This will be combined with a distillation method, along with adversarial training and data augmentation, to remove and reduce the impact of non-robust features in the input training dataset as well. The result will be a complete framework that will enable the detection of non-robust features in the data/model with interpretable information regarding the different vulnerability sources in the model and the data. Finally, we will incorporate the Neural Cleansing with Neural Architecture Search, to enable the adaptation of the model architecture to find the optimal trade-offs between robustness and accuracy; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Keutzer, Kurt*

Learning Video Models Using VQ-VAE and Transformers – Developments in generative modeling for natural images have seen tremendous progress over the last few years, where SOTA generative models are able to produce realistic, diverse, and high-resolution samples from complex image datasets. Generating complex videos presents itself as a further challenge for the area of generative modeling, primarily due to increased data and computational complexity. In comparison to images, generating high-fidelity and coherent video samples requires a generative model to learn about motion, object interactions, and perspective, all of which are necessities for bringing intelligence into the real world. Applied to the real world, video generation models can be extended to a suite of conditional generative video models that can be used for a wide variety of tasks, such as future video prediction, forecasting semantic abstractions for autonomous driving [20], and world modeling; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Abbeel, Pieter*

Meta Neural Architecture Search For Computer Vision – Many state-of-the-art algorithms for computer vision tasks such as classification, object detection, and semantic segmentation are based on Deep Neural Networks (DNNs). These tasks are critical in autonomous driving settings and highly efficient DNN architectures are required in order to deploy these DNNs in such settings. Neural architecture search (NAS) algorithms aim to automatically find appropriate DNN architectures for these tasks and deployment environments, e.g. by taking into account target hardware constraints. In this work, we propose to address two fundamental problems when applying NAS to autonomous driving systems: (i) the ability to transfer existing NAS to new domains and tasks with less labeling, and (ii) simultaneously applying NAS to multi-task and multi-domain settings. To address these problems, we propose to research and develop Meta Neural Architecture Search (M-NAS), which aims to learn a task-agnostic representation that can be used to improve the architecture search efficiency for a large number of tasks. The key idea for M-NAS is to treat a "super-network" as a meta architecture, where each sub-network is viewed as a component for a task/data-specific architecture, and then design a meta-search strategy to find the optimal architecture for each new task and data domain. In this formulation, the meta-search strategy can be used to simultaneously train and search a common architecture for multi-task and multi-domain environments, as well as provide a search strategy for additional training on new tasks and data domains; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Keutzer, Kurt*

Offline Reinforcement Learning for Data-Driven Autonomous Driving – Reinforcement learning has emerged as a highly promising technology for automating the design of control policies. Deep reinforcement learning in particular holds the promise of removing the need for manual design of perception and control pipelines, learning the entire policy -- from raw observations to controls -- end to

end. However, reinforcement learning is conventionally regarded as an online, active learning paradigm: a reinforcement learning agent actively interacts with the world to collect data, uses this data to update its behavior, and then collects more data. While this is feasible in simulation, real-world autonomous driving applications are not conducive to this type of learning process: a partially trained policy cannot simply be deployed on a real vehicle to collect more data, as this would likely result in a catastrophic failure. This leaves us with two unenviable options: rely entirely on simulated training, or manually design perception, control, and safety mechanisms. In this project, we will investigate a third option: fully off-policy reinforcement learning, also referred to as offline reinforcement learning. Our recent work has seen the development of radical new algorithms for offline RL that substantially improve on the state of the art in reinforcement learning from logged data [1, 2], which I discuss in this recent article. The aim of this project will be to extend and apply these techniques to learning driving policies, both in a simulated evaluation using Carla, and using real data in the BDD100k dataset. To our knowledge, this would be the first attempt at large-scale offline reinforcement learning for a realistic autonomous driving application. If successful, this research would yield an entirely new way to acquire autonomous driving policies that are trained end-to-end, without the dangers of real-world RL, the engineering cost of sim to real transfer, or the data collection burden of imitation learning (since offline RL can learn from suboptimal data); *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Levine, Sergey*

Pedestrian Trajectory Prediction Combining Posture and Social Features – A primary goal of this study is to explore the combined utilization of social and gesture features based on a machine learning method to predict pedestrian trajectories. A deep three-dimensional convolutional neural network (3D-CNN), with its non-linear attributes, is an appropriate candidate method to effectively achieve the objective of predicting pedestrian trajectory. The second goal of this work, from a methodological perspective, is to introduce a novel way of using 3D-CNN, which is mostly limited to applications for lidar and camera data processing in the field of autonomous driving. Additionally, we will expand the versatility of OpenPose, which can be used for the extraction of posture features and prediction of future movements; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Chan, Ching-Yao*

Self-supervised Representation Learning for Autonomous Driving – In this project, we propose methods for better ways of training deep models to force them to generalize to diverse real data scenarios. The idea is to make the learning algorithms work harder at training time by using self-supervision to discover the regularities in the data, instead of just memorizing the training set, as is often done now with supervised learning. In 2021, we propose to continue harnessing the power of temporal self-supervisory signals found in unlabeled video data (such as driving videos). We plan to use the cycle-consistency loss on palindrome videos for training models that will learn to perform tracking and long-range optical flow without any supervision. Because our models do not use any supervision, we will also use them at test time, which will allow us to be more robust to smooth domain changes (e.g. time-of-day, weather, urban vs. rural, etc); *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Efros, Alexei*

Similarity Learning for Multiple Object Tracking – Similarity learning has been recognized as an crucial step for object tracking. However, existing multiple object tracking methods only use sparse ground truth matching as the training objective, while ignoring the majority of the informative regions on the images.

In this project, we develop and extend Quasi-Dense Similarity Learning, which densely samples hundreds of region proposals on a pair of images for contrastive learning. We can naturally combine this similarity learning with existing detection methods to build Quasi-Dense Tracking (QDTrack) without turning to displacement regression or motion priors. We have found that the resulting distinctive feature space admits a simple nearest neighbor search at the inference time. Despite its simplicity, QDTrack outperforms all existing methods on MOT, BDD100K, Waymo, and TAO tracking benchmarks; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Darrell, Trevor*

Spatio-temporal 3D reconstruction of Pedestrians, Objects, and the Environment from Self-Driving Data – Understanding pedestrian behavior in self driving requires 3D analysis of the pedestrian in question, but also the 3D location and pose of other pedestrians and objects, such as cars, vegetation and the road, in the scene. Yet, today's 3D human mesh recovery techniques mostly focus on the 3D reconstruction of a single person in isolation. In this work, we will propose an approach that can reconstruct the entire scene in 3D, including the people, objects, and the environment from self-driving data over time. This approach will incorporate the 3D context (road, objects, other people) in order to recover a physically consistent dynamic 3D scene reconstruction via utilizing the LiDAR data. Resulting 3D reconstructions of humans and objects will be useful for multitude of applications such as pedestrian path prediction, data simulation, and learning a data-driven interaction prior between humans and objects that can be used for monocular image analysis; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Kanazawa, Angjoo*

Real-time and Accurate Object Detection through Systematic Quantization of Transformer and MLP-based Computer Vision Models – Mainstream Deep Learning research focuses on improving the accuracy of neural networks (NNs); however, most real-world applications have real-time constraints which enforce latency constraints on the inference of the NN. In particular, in autonomous driving applications it is absolutely essential that NNs meet their latency constraints. To compound this challenge, many automotive applications must run on edge processors with limited computational power. For this reason, practitioners have been forced to use shallow networks with non-ideal accuracy to avoid the latency problem. One promising solution to this problem is to quantize the weights and activations of a NN model, so that it can be fit into an embedded hardware and provide additional opportunities for parallel execution. However, most current quantization methods involve random heuristics and require high computational cost associated with brute-force searching. In addition, these meth- ods typically target CNN-based compact models, while recent state-of-the-art NN on vision tasks have more parameters, and many are based on the transformer [1,2] or the MLP [3,4] architectures. Our goal here is to use second-order information (Hessian) to systematically quantize the NN model. So far we have developed two Hessian-based quantization frameworks, HAWQ [5,6] and ZeroQ [7,8]. In this proposal we plan to extend these frameworks by: (i) developing a better quantization strategy for large neural networks with state-of-the-art performance on object detection, (ii) developing quantization-friendly operations in transformer-based or MLP-based neural network models, (iii) extending ZeroQ/HAWQ to automatically decide the neural architecture together with the quantization bitwidth, and (iv) extending ZeroQ/HAWQ framework to ultra- low precisions such as binary or ternary quantization; *Project Sponsor: BDD; Funding Amount: $45,000.00; Date Completed: 2022-05-31; Principal Investigator: Keutzer, Kurt*

Safety Evaluation of Automated Driving Systems – Automated driving systems (ADS) have been developed and marketed in recent years and likely will be further deployed in the coming years. In this study, we aim at formulating a systematic model for safety risk estimation, particularly if the targeted ADS is new to the market and there is no comprehensive data to support convincing safety performance. It could assist public agencies in seeking a balance of risk and benefits when evaluating or accepting the deployment of ADS in its community; *Project Sponsor: BDD; Funding Amount: $90,000.00; Date Completed: 2022-05-31; Principal Investigator: Chan, Ching-Yao*

Self-supervised Visual Pre-training for Motor Control – We show that self-supervised visual pretraining from real-world images is effective for learning complex motor control tasks from pixels. We train the visual representation by masked modeling of natural images. We then integrate neural network controllers with reinforcement learning on the frozen representations. We do not perform any task-specific fine-tuning of the encoder;the same representations are used for all motor control tasks. To accelerate progress in learning from pixels, we contribute a benchmark suite of hand-designed tasks varying in movement types,scenes, and robots. To the best of our knowledge,ours is the first self-supervised model to exploit natural images at scale for motor control. With-out relying on labels, state-estimation, or expert demonstrations, our approach consistently outper-forms supervised baselines by up to 80% absolute success rate, sometimes even matches the oracle state performance. We also find that the choice of visual data plays an important role; e.g., images of human-object interactions work well for manip-ulation tasks. Finally, we show that our approach generalizes across robots, scenes, and objects. Our effort will release models and evaluations; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2022-05-31; Principal Investigator: Darrell, Trevor*

Sequence Modeling as Reinforcement Learning – Reinforcement learning is typically approached from the perspective of value estimation or policy gradients. However, at its core, we can also regard reinforcement learning as essentially a sequence modeling problem: the goal is to determine a sequence of actions from sequentially observing states that lead to a desired outcome. This perspective on the reinforcement learning problem is interesting because recent years have seen tremendous advances in sequence modeling (e.g., language modeling, Transformers, GPT-3, etc.), and the prospect of leveraging such advances to enable simpler and more scalable RL techniques is highly appealing. Indeed, such methods could enable a set of capabilities that may make reinforcement learning significantly more practical to apply to autonomous driving applications: effective sequence models applied to driving data would provide not only a way for autonomous vehicles to make effective decisions about what to do to attain navigational goals, but also learned “agent simulators” that can be used to forecast the behavior of other vehicles on the road, and even model other agents such as pedestrians. The fact that all of this could be done with essentially the same set of algorithmic and modeling tools is also highly desirable. Thus, the goal of this research project will be to develop a framework for reinforcement learning for autonomous driving applications centered around sequence modeling, and evaluate this framework simultaneously for model-based RL and for multi-agent forecasting applications, including forecasting of other vehicles and pedestrians; *Project Sponsor: BDD; Funding Amount: $90,000.00; Date Completed: 2022-05-31; Principal Investigator: Levine, Sergey*

Simultaneous On-Target Domain Adaptation and Performance Prediction – Building machine learning models that perform reliably in a wide range of environments is a central challenge for machine learning researchers. Research on the problem of unsupervised domain adaptation aims to develop approaches

which improve a model's performance in new domains by means of adaptation. While work on automatic model evaluation attempts to estimate a model's accuracy over unlabeled test data from a new domain. However, predicting a model's accuracy after adapting the model to a new domain comes with a new set of challenges. Being able to reliably improve a model's performance in a novel domain and accurately estimate its real accuracy is an important step towards developing more reliable machine learning systems. We have developed a method for performance prediction that is practical and scalable; *Project Sponsor: BDD; Funding Amount: $90,000.00; Date Completed: 2022-05-31; Principal Investigator: Darrell, Trevor*

An efficient framework of developing video-based driving simulation for traffic sign evaluation – The driving simulator is a widely adopted experimental platform for investigating human-factors questions related to traffic signs and other traffic control devices in a safe environment. This paper presents a methodological framework for developing a video-based simulation program for traffic-sign evaluation; *Project Sponsor: BDD; Funding Amount: ; Date Completed: 2022-02-28; Principal Investigator: Wang, Peggy*

Plan, Book, and Pay For Demand-Responsive Transit Agencies In CA, OR, and WA – The investigators in this project plan to develop, simulate and test, through targeted vehicle and roadway infrastructure field test experiments, a traffic operating system that organizes existing computation, communication and automotive technologies to: (1) minimize congestion by increasing traffic throughput; (2) enhance safety by reducing driver errors through the use of cooperative adaptive cruise control (CACC) strategies that significantly increase arterial traffic throughput while preserving safety; and (3) contain the cost of parking by minimizing the number of idle vehicles and the number of vehicles searching for parking. These goals are achieved through integration of traffic measurements with the traffic management on vehicle, road link and network levels, making effective use of a dynamic traffic model and simulation. The project will demonstrate how three levels of traffic control are interconnected and we will develop new simulation and control design techniques that receive each other's output as feedback signals; *Project Sponsor: California Association for Coordinated Transportation, Inc (CAL ACT); Funding Amount: $75,000.00; Date Completed: 2022-02-20; Principal Investigator: Kurzhanskiy, Alex*

Operations Planning ToolBox – The Operations Planning Toolbox (OPT) is a project to develop a user-friendly, well-documented, open-source, multi-modal transportation modeling software for quick quantitative assessment of operational scenarios in terms of mobility and safety, provided as a desktop application, supported by UC Berkeley PATH. This new software, a mesoscopic simulator, will support the fast execution of the analysis of freeway and corridor operations as well as highways and multi-lane road analysis; *Project Sponsor: Caltrans; Funding Amount: $560,000.00; Date Completed: 2021-02-28; Principal Investigator: Kurzhanskiy, Alex*

Factual, Controllable, and Interactive Dialogue Agents – Advances in language models have made it possible to generate highly plausible human-like text. However, the leap from believable and realistic text generation to controllable and useful dialogue agents requires addressing a number of additional challenges. The objective of this project is to leverage tools in reinforcement learning to address these challenges, developing dialogue agents trained with a combination of language modeling and value-based reinforcement learning to optimize long-horizon objectives in human-interactive settings; *Project Sponsor: BDD; Funding Amount: $100,000.00; Date Completed: 2024-05-31; Principal Investigator: Levine, Sergey*

Demonstrations of proof-of-concept experiments

I-210 Hard Pilot Deployment and Operation ICM 5 -Revised – The Connected Corridors Program is an integral component of Caltrans's commitment to transportation systems management. The objective of this phase is to develop and demonstrate key elements of Connected Corridors research. This includes completion of the technical design, implementation of the estimation function, system integration, and the launch and operation of the I-210 pilot.; *Project Sponsor: Caltrans; Funding Amount: $7,000,000.00; Date Completed: 2021-12-31; Principal Investigator: Bayen, Alex*

CIRCLES: Congestion Impact Reduction via CAV-In-The-Loop Lagrangian Energy Smoothing – The main project goal is to demonstrate, for the first time, that reduced fuel consumption of all vehicles in the traffic stream can be achieved using intelligent control of a small number of connected and automated vehicles (CAVs) in the traffic stream. The approach focuses on new energy-aware theory for mobile traffic control (i.e. using a few vehicles as traffic controllers via CAV technology), to i) improve the energy efficiency of traffic flow; and ii) integrate mobile automation with static infrastructure to further optimize energy efficiency. The demonstrated technology is estimated to result in energy gains exceeding 10% for all vehicles on the road, through automation of less than 5% of the vehicles in the flow. This estimate is based on prior field experiments demonstrating fuel consumption reductions of up to 40% on a single lane track, which we expect to be reduced due to the response of other drivers and higher complexity.; *Project Sponsor: Department of Energy ; Funding Amount: $3,499,000.00; Date Completed: 2023-12-31; Principal Investigator: Bayen, Alex*

Traffic Flow control with Multi-agent learning – This project spans two years. The deliverables for year one are:1) The development of a mixed autonomy model for semi-autonomous vehicle fleets (delivery in particular; 2) The development of end-to-end pixel deep-RL learning algorithms for traffic flow control via (a) static assets; (b) multi-agent algorithms; 3) The development of a FLOW benchmark case for the city of Riyadh (with local data); and 4) The integration of FLOW with Grand Theft Auto-like tools (e.g. Carla), to test machine vision based sensing in lieu of rendering based sensing for learning. In year two, the goals will be: 1) Vehicle based tests of deep-RL based algorithms; 2) Validation of approach using collected field data from the KSA based using multi-agent based algorithms; 3) Demonstration of large-scale flow smoothing in mixed autonomy traffic 3.2.3. to be postponed to full installment; *Project Sponsor: King Abdulaziz City for Science and Technology; Funding Amount: $400,000.00; Date Completed: 2023-03-31; Principal Investigator: Bayen, Alex*

Cooperative Adaptive Cruise Control Development and Test of Heavy-Duty-Truck for Self-Driving – The objective of this project is to develop and demonstrate 20truck CACC in Saudi Arabia with the first truck driven completely manually in steering control and acceleration/braking control. The second truck will be automatic or controlled by computer to follow the first truck with pre-selected constant T-Gap. Main tasks include control system development for the truck on KACST, truck longitudinal dynamics modeling, feedback control design and simulation, control algorithm implementation, tuning, and field test and demonstration; *Project Sponsor: King Abdulaziz City for Science and Technology; Funding Amount: $499,999.00; Date Completed: 2020-09-23; Principal Investigator: Bayen, Alex*

FHWA Truck Platooning Early Deployment Assessment Phase 2 – The "Truck Platooning Early Deployment Assessment: Phase 2" project spearheaded by Dr. Xiao-Yun Lu and supported by John Spring, Dr. Hao Liu, and others was intended to find out the gaps in several aspects towards the deployment of partially automated truck platooning for daily freight movement for long distance hauls.

Those aspects include but not limited to: (1) technical gaps such as performance of the Adaptive Cruise Control (ACC) for the lead truck and the Cooperative ACC (or CACC) for the follower trucks, for a varieties of practical truck operation conditions; (2) reliability of the overall system; (3) safety in operation those trucks in public traffic for long distance haul; (4) driver behavior in operation of those trucks; (5) dispatch logistics by the freight operator; (6) institutional issues for the operation of partial automated truck platooning with much short time-gap crossing several states with respect to speed limit, permit, weigh station, and attention of other road users, etc.; and (7) additional sensor onboard data collection to capture the interactions with other nearby traffic. During this research effort, PATH installed integrated ACC and CACC technology, additional sensors, driver monitoring systems, real-time remote monitoring system, and a suite of data collection equipment into four new Volvo trucks which were planned to be driven daily by Roly's Trucking drivers' along the I-10 Corridor. The PATH team also designed a Field Operational Test Plan, driver recruitment and training processes. The PATH project team has accomplished most of the tasks of the project. However, due to some technical difficulties/issues in the lower level control actuation, the project did not have enough time and resources to conduct the field operational test which need to be done in the future. California PATH and its team are building upon previous truck platooning efforts funded under the Federal Highway Administration's Exploratory Advanced Research Program. During this project, PATH was supported by a team of industry experts including Westat, Cambridge Systematics, and fleet partner Roly's Trucking. The final report and seven white papers for this project were recently completed and approved by the United States Department of Transportation (USDOT).; *Project Sponsor: Caltrans; Funding Amount: $374,999.00; Date Completed: 2023-02-27; Principal Investigator: Lu, Xiao-Yun*

Field Test of Combined Coordinated Ramp Metering and Variable Speed Advisory for Freeway Traffic Control – The UC Berkeley PATH project team has developed a simple, practical VSA algorithm that should improve bottleneck flow and reduce shockwaves along the freeway. The objective is to field implement, test, and evaluate the performance of combined CRM and VSA data learned from previous Caltrans projects on SR 99 NB corridor in Caltrans District 3 in Sacramento. During a 12-month field test stage, dynamic interactions of CRM and VSA in a real-world freeway corridor will be investigated. The radar speed data from these VSA signs and the speed data collected from the dual loop detectors/2070 controllers will be used to evaluate the driver compliance rate. Performance improvements for joint functions of CRM and VSA will be quantified using river compliance; *Project Sponsor: Caltrans; Funding Amount: $550,000.00; Date Completed: 2021-02-28; Principal Investigator: Lu, Xiao-Yun*

Field Test of Combined Coordinated Ramp Metering and Variable Speed Advisory for Freeway Traffic Control – The objective of this project is to field implement, test, and evaluate the performance of Combined CRM and VSA on SR 99 NB corridor in caltrans District 3 in Sacramento. The project will use a series of roadside VSA signs along the corridor and one or two changeable message signs (CMS) in the upstream section to acknowledge the public driver in advance about the VSA and CRM downstream to gain better driver compliance rate. The project will also develop a website displaying various collected data that can be accessed by the public; *Project Sponsor: Caltrans; Funding Amount: $550,000.00; Date Completed: 2022-04-29; Principal Investigator: Lu, Xiao-Yun*

Application Development for Connected Fleet – The applications developed under this project will improve the coverage and flexibility for deploying V2I safety applications to enhance road safety and worker safety near traffic hazard areas; *Project Sponsor: Caltrans; Funding Amount: $200,000.00; Date Completed: 2023-02-28; Principal Investigator: Zhou, Kun*

ITS ePrimer Module 5: ITS to Support Travelers – ITS technologies offer an array of applications and enhancements for multimodal transportation, from real time information to safety applications and driver conveniences. This module describes the capabilities, features, and limitations of ITS technologies for multimodal transportation that enhance safety and mobility, and reduce excess fuel consumption and emissions. https://www.pcb.its.dot.gov/eprimer/module5.aspx#bookmark0; *Project Sponsor: USDOT and ITE; Date Completed: 2022-06-30; Principal Investigator: Skabardonis, Alex*

3D Object Detection Enhanced by Temporal Multi-View Input – We propose a flexible temporal multi-sensor fusion solution to 1) improve fast moving object detection under noisy sensor calibration, 2) make full use of existing sensors to enable accurate, robust, and general 3D detection to enable more capabilities such as very close obstacle detection and narrow scene perception etc., and 3) deploy our model into the auto-labeling pipeline; *Project Sponsor: BDD; Funding Amount: $80,000.00; Date Completed: 2024-05-31; Principal Investigator: Tomizuka, Masayoshi*

References

1. “H.R.200 – 117th Congress (2021-2022): Infrastructure Investment and Jobs Act.” Congress.gov, Library of Congress, 4 June 2021, https://www.congress.gov/bill/117th-congress/house-bill/3684.
2. “California plans to spend $37 billion fighting climate change”. LAtimes.com, 13 January 2022, https://www.latimes.com/environment/newsletter/2022-01-13/heres-how-california-plans-to-spend-22-billion-fighting-climate-change-boiling-point
3. “California Releases World’s First Plan to Achieve Net Zero Carbon Pollution.” Gov.ca, 16 November 2022, https://www.gov.ca.gov/2022/11/16/california-releases-worlds-first-plan-to-achieve-net-zero-carbon-pollution/
4. “Transportation Trends 2022–23.” Deloitte.com, 8 November 2022, https://www2.deloitte.com/us/en/insights/industry/public-sector/transportation-trends.html
5. “Biden-Harris Administration Opens Applications for First Round of $2. 5 Billion Program to Build EV Charging in Communities & Neighborhoods Nationwide.” U.S. Department of Transportation, 14 March 2023, https://content.govdelivery.com/accounts/USDOT/bulletins/34ea9a9
6. “Six Major Automakers Agree to End Gas Car Sales Globally by 2040.” CarandDriver.com, 10 November 2021, https://www.caranddriver.com/news/a38213848/automakers-pledge-end-gas-sales-2040/
7. “Caltrans Unveils Vision for Future of Transportation.” California Department of Transportation, 2 March 2021, https://dot.ca.gov/news-releases/news-release-2021-005.
8. “California Enacts World-Leading Plan to Achieve 100 Percent Zero-Emission Vehicles by 2035, Cut Pollution.” Gov.ca, 25 August 2022, https://www.gov.ca.gov/2022/08/25/california-enacts-world-leading-plan-to-achieve-100-percent-zero-emission-vehicles-by-2035-cut-pollution/
9. “Fast Facts on Transportation Greenhouse Gas Emissions.” United States Environmental Protection Agency, 13 June 2023, https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions
10. “California Job Growth.” Department of Numbers, 16 June 2023, https://www.deptofnumbers.com/employment/california/
11. California Transportation Plan 2050” California Department of Transportation, 3 February 2021, https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/ctp-2050-v3-a11y.pdf
12. “California's Population - Public Policy Institute of California.” Public Policy Institute of California, January 2023, https://www.ppic.org/publication/californias-population/
13. “Climate Action Plan for Transportation Infrastructure (CAPTI)” California State Transportation Agency, 10 March 2021, https://calsta.ca.gov/subject-areas/climate-action-plan
14. “Autonomous Vehicle Collision Reports.” State of California Department of Motor Vehicles, 27 June 2023,

https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-collision-reports/

15. “Drivers Hit and Killed More Than 7,500 Pedestrians Last Year, Most Since 1981, New Projection Shows.” Ghsa.org, 22 June 2023, https://www.ghsa.org/resources/newsreleases/GHSA/Pedestrian-Spotlight-Full-Report23
16. “Road to Zero: A Plan to Eliminate Roadway Deaths.” Nsc.org, 15 June 2023. https://www.nsc.org/road/resources/road-to-zero/road-to-zero-home#:~:text=The%20Road%20to%20Zero%20Coalition%2C%20managed%20by%20the,fatalities%2C%20which%20recently%20increased%20after%20years%20of%20decline.
17. “High-Speed Rail in California.” California High Speed Rail Authority, 1 July 2023. https://hsr.ca.gov/high-speed-rail-in-california/
18. “Emerging Technologies in Transportation.” California Partners for Advanced Transportation Technology. 20 April 2023.

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