TASK FORCE ON AUTONOMOUS VEHICLES

Framing the Future for Autonomous Vehicles in Oregon

MEMORANDUM

To: Task Force on Autonomous Vehicles, Subcommittee on Road and Infrastructure Design
From: ODOT Staff
Date: March 28, 2019
Re: State Efforts on Infrastructure for Connected and Automated Vehicles

Background Information

The Intersection of Connected and Automated Vehicle Technology
Manufacturers are separately developing automated vehicle (AV) and connected vehicle (CV) technologies, and a few have indicated their intention of producing AVs that can operate without any communication links to other vehicles or infrastructure. However, many researchers and industry experts anticipate that in the future vehicles will be both automated and connected, and that combining these technologies will maximize the potential safety and mobility benefits.

Road operators and AV manufacturers are beginning to discuss potential changes to road infrastructure and design that could enable or improve AV operation, such as higher-contrast pavement markings. Infrastructure changes necessary for CVs are better understood, but have also encountered barriers to deployment.

Competing Connected Vehicle Communications Technologies
Connected vehicles use wireless communications systems to exchange messages with other vehicles and the driving environment. Vehicle-to-vehicle (V2V) communications refer to messages sent between vehicles, while vehicle-to-infrastructure (V2I) refers to messages exchanged with roadside equipment; the term vehicle-to-anything (V2X) refers broadly to any type of connected vehicle communication, including communications with vehicles, infrastructure, or even cell phones.

Connected vehicles could rely on one of two communications technologies: dedicated short range communications (DSRC) or cellular technology. DSRC is an open-source protocol for wireless communication that can send messages with low latency and limited interference from radio or adverse weather conditions.

Connected vehicles could also rely on 5G cellular technology, which is still under development. 5G cellular technology also has the potential to transmit with low latency and could allow for more features and flexibility. 5G cellular technology has gained currency among a number of automakers and telecom providers in recent years.

In 2016, the National Highway Traffic Safety Administration (NHTSA) and U.S. DOT initiated the federal rulemaking process to mandate use of DSRC radios in all new light vehicles by 2023, but the current administration has delayed this process and taken a technology-neutral approach to regulation. Some auto manufacturers have committed to DSRC, while others are focused on 5G. The ongoing lack of

certainty around vehicle equipment and communications protocol has made it difficult for transportation agencies to spend limited funds on roadside CV infrastructure.

State Efforts on Infrastructure for Connected and Automated Vehicles

This memo highlights a few efforts by states and local jurisdictions to prepare for or pilot infrastructure innovations related to connected and automated vehicles. The list below is intended to provide an overview of the variety of infrastructure projects underway and is not comprehensive.

FIBER

Colorado's Smart Mobility Plan and Statewide Strategic Fiber Plan (20+ years)
Over the past 20 years, Colorado DOT has installed or acquired approximately 1,400 miles of fiber optic cable. In some cases, Colorado DOT installed the fiber themselves, but in many cases they partnered with public and private entities, requiring that they install fiber in exchange for access to and use of the right-of-way. Colorado's Statewide Strategic Fiber Plan is intended to create a "carrier grade network" and improve critical communications facilities.

Colorado DOT recently established a 5-10 year Smart Mobility Plan to prepare the agency's "assets, data management, communications systems, and infrastructure to maximize the benefits of connected and autonomous vehicles." One element of the plan is to install fiber optic cable along "Smart Mobility Corridors." For example, in January Colorado DOT began installing 17 miles of fiber optic cable along US 24. The fiber will enable real-time access to traffic monitoring cameras, variable message signs, and traffic signals. In the future, it may also be accessible to automated vehicles and enable communication with connected vehicles.

Link: https://www.codot.gov/programs/operations/intelligent-transportation-systems/infrastructure/planning

Utah's Fiber-Optic Broadband Expansion Agreements (20+ years)
In 2008, Utah passed a law defining 30-year shared-use agreements with telecom services to coordinate fiber-optic broadband network development in the public right of way along state roads. UDOT policy allows telecom providers to get easy access to the right of way for continuous build-outs, which prevents any one company from having exclusive access to the right of way. UDOT installs fiber during all roadway projects in anticipation of future needs, including providing high-speed internet access to local jurisdictions and enabling operation of CVs and AVs. Utah's goal is to connect every traffic signal and equip all roadways with communications infrastructure to provide information on roadway and weather conditions.

Link: https://www.fhwa.dot.gov/policy/otps/successprac.cfm

INFRASTRUCTURE TO ENABLE AV NAVIGATION

California's 6-inch Striping on I-5 (2018)
Last year, California's Department of Transportation (Caltrans) replaced striping along I-5 to increase visibility for both human drivers and automated driving systems. Caltrans widened the stripes from four inches to six inches and used thermoplastic or tape-like material rather than paint. The thermoplastic and tape contain tiny glass beads that are highly reflective and improve visibility at night and during inclement weather.

According to Donald Anderson, deputy director for maintenance and operations at Caltrans, automated vehicle manufacturers have indicated that wider stripes could help automated vehicles more accurately and reliably identify and respond to pavement markings. Preliminary results of *NCHRP 20-102(06): Road Markings for Machine Vision* indicated that high contrast is vital for automated vehicles' camera and sensor systems. The International Society of Automotive Engineers (SAE) has also convened a committee to research potential changes to infrastructure, and one of the topics under consideration is pavement markings.

Link: https://www.ttnews.com/articles/stripes-california-highway-pave-way-self-driving-vehicles

Las Vegas' Digitized Roadways (2018-2019)
The Regional Transportation Commission of Southern Nevada (RTC) has partnered with INRIX to "digitize" key roads in Las Vegas. This process involves using INRIX AV Road Rules software to convert local map data and traffic rules into data usable by automated vehicles. This data can be used by automated vehicles to improve their functionality and make sure they can comply with local rules, such as school zones. The system also allows data from automated vehicles to be used to identify needs such as missing signage or striping.

RTC is the leading road authority in using this technology, but INRIX is working with other jurisdictions such as Boston, MA and Austin, TX.

Link: http://inrix.com/press-releases/av-road-rules-rtc/

TRAFFIC MANAGEMENT

New York City Connected Vehicle Pilot (2018-2020)
Part of USDOT's Connected Vehicle Pilot Deployment Program, The New York City Connected Vehicle Project has been evaluating the safety benefits of CV technology and challenges to the deployment of the technology, especially those specific to dense urban areas. The pilot has equipped approximately 8000 vehicles with CV devices. Most of these vehicles are taxis, city buses or and other fleet vehicles. There are approximately 350 intersections equipped with RSUs. New York City Department of Transportation is using V2I and V2V communication to test safety alerts, such as alerts about sudden braking areas, and compliance messages about speed and red light violations.

The project is evaluating techniques to combat difficulties with location data that arise from NYC's "urban canyons." These methods involve dead reckoning, CAN bus integration, triangulation and others. Early testing of these efforts is said to be encouraging. The pilot has also tested an over the air update process using the DSRC technology that is deployed on the pilot vehicles and infrastructure. The NYC pilot began in August of 2018 and will continue until February 2020.

Link: https://cvp.nyc/

Tampa-Hillsborough Expressway Authority Pilot (2018-2020)
Also part of USDOT's Connected Vehicle Pilot Deployment Program, The Tampa-Hillsborough Expressway Authority will pilot V2V and V2I technology to improve traffic congestion and safety, especially by reducing the risk of rear-end and wrong-way collisions, in downtown Tampa, FL.

Rear-end crashes are a significant problem on Tampa's Lee Roy Selmon Expressway. This pilot will use V2V among participating vehicles to warn drivers of upcoming slowdowns in traffic to combat this problem. The Expressway also features a reversible lane. This has contributed to wrong-way collisions. V2I communications will be deployed to issue warnings to potential wrong-way drivers. The V2I and V2V infrastructure will also be used for pedestrian safety, signal timing, traffic monitoring and other applications. The pilot will include 1600 private cars, 10 buses, 10 streetcars, 500 pedestrians and 40 RSUs. The pilot began operation in 2018 and will conclude in January 2020.

Link: https://www.tampacvpilot.com/

Michigan's Connected Vehicle Test Beds (2012-Present)
The University of Michigan researches and tests CV technology at Mcity, a 32-acre mock city constructed as a proving ground for AV and CV technology. The University has also established several on-road, real-world test beds in southeast Michigan: in Ann Arbor, Detroit, Farmington Hill, and Southfield. The Ann Arbor Connected Vehicle Test Environment is intended to be the largest operational CV deployment in the world. It began in 2012 with a three year pilot involving 73 lane miles, 25 roadside units, and approximately 2,800 vehicles, but has now been expanded with the goal of connecting 45 street locations, 12 freeway sites, 27 square miles around the City of Ann Arbor, and up to 5,000 equipped vehicles. Using DSRC technology, the vehicles and roadside infrastructure exchange information about vehicle position, speed, direction of travel, crash warnings, ice warnings, intersection movement assit, curve speed warning, red light violation, and pedestrian detection.

Link: https://mcity.umich.edu/our-work/on-the-road/

FREIGHT

Wyoming DOT Connected Vehicle Pilot (2014-Present)
Wyoming's I-80 is a major freight corridor, but dangerous winter driving conditions lead to many truck blowovers and crashes every year. Through U.S. DOT's Connected Vehicle Pilot Deployment Program, Wyoming DOT is developing a system that uses V2I and V2V communications technology to improve safety and reliability for trucks traveling along I-80.

When the pilot is complete, Wyoming DOT will have installed approximately 75 roadside units (RSUs) and 400 on-board units (OBUs), including 100 on Wyoming DOT fleet vehicles and at least 150 on commercial trucks. The RSUs and OBUs communicate via DSRC technology. This technology will enable forward collision warnings, distress notifications, and alerts about speed restrictions, vehicle restrictions, weather conditions, road conditions, road closures, work zones, and crashes further down the road.

Link: https://wydotcvp.wyoroad.info/

CONNECTED VEHICLE ECOSYSTEM

Panasonic Partnership with Colorado DOT (2016-Present) and Utah DOT (2019-Present)
In 2016, Colorado DOT contracted with Panasonic to build a connected vehicle ecosystem, in which connected vehicles and infrastructure will be able to share data in real time. The ecosystem will also provide information to roadway operators, who can then provide road users with up-to-date alerts and better manage the transportation system. The goal is to improve safety, mobility, and reliability of Colorado's transportation system, especially once more connected and automated vehicles are on the roads.

Colorado DOT and Panasonic are outfitting fleet vehicles with communications equipment and installing roadside infrastructure along a 90-mile stretch of I-70, with 400 more miles of coverage planned for the near future. Panasonic is also developing a data processing platform capable of handling the large volume of messages that will be generated by connected vehicles and infrastructure when they are widely deployed.

In June 2019, Utah DOT announced a similar 5-year, multi-phase partnership with Panasonic to develop an advanced transportation data network. Like Colorado, Utah DOT will begin by outfitting 30 fleet vehicles with communications technology and deploying approximately 40 roadside units to enable vehicle-to-infrastructure communications.

Link: https://www.codot.gov/news/2016-news-releases/11-2016/panasonic-to-partner-with-colorado-department-of-transportation-to-build-connected-transportation-future

Link: https://www.govtech.com/products/Utah-Grows-Connected-Vehicle-Work-with-Panasonic-Partnership.html

STRATEGIC PLANNING

Minnesota DOT's Connected and Automated Vehicle Strategic Plan

In July 2019, Minnesota DOT published its Connected and Automated Vehicle (CAV) Strategic Plan, a document designed to prepare Minnesota's transportation system for rapid advancements in technology and mobility precipitated by the deployment and connected and automated vehicle technology. The plan identifies nine focus areas, including operations and maintenance, strategic staffing, and multimodal transportation. The plan also offers strategies relevant to road and infrastructure design. It is recommended that Minnesota DOT:

- Strategically build out fiber optic and communications infrastructure to support CAV and transportation systems management and operations (TSMO)
- Update design standards to account for truck platooning
- Pilot pavement marking projects that support human drivers and CAV
- Invest in electric vehicle infrastructure at state facilities
- Continue investments in connected vehicle test corridors to determine the resources necessary to design, operate and maintain these technologies in urban and rural environments
- Identify CAV strategies that will enhance MnDOT operations and improve traffic safety and operations
- Identify skill gaps needed to support CAV technologies, update civil service requirements, and develop a CAV talent pipe

Link: http://www.dot.state.mn.us/automated/docs/cav-stategic-plan.pdf

Impacts Assessment to Prepare for Future Transportation System

Impact Area: Broadband Infrastructure	
Description	Broadband infrastructure is an enabling technology for future Connected Vehicle applications, so technically, it is not a direct requirement to support automated driving. However it is an important supporting element for connected vehicle applications that will be beneficial for automated driving.
Certainty/potential time horizon	There is lack of industry direction right now due to competing connected vehicle technologies, lack of regulatory requirements, and competition for the 5.9 GHz spectrum. Therefore, significant deployment of vehicle to vehicle and vehicle to infrastructure applications will continue to be pushed toward the future as some of these questions get resolved.
Co-benefits/advancing established goals	Broadband infrastructure has other uses for Intelligent Transportation Systems (ITS) applications and connecting traffic signals. So installation of fiber optic cable to connect equipment offers benefits today along with preparing for future connected vehicle applications. This topic aligns with a current Governor's Office initiative to improve rural broadband access, so there may be opportunities for collaboration with that initiative.
Barriers	The primary barrier to installation of broadband infrastructure along highway right-of-way is the added cost to projects. Other states have been able to leverage the value of access to highway right-of-way to get private investment to install fiber optic cable and provide some fiber strands for transportation use. In Oregon, state law provides utilities free access to

	right-of-way for installation of broadband infrastructure.
Impact to infrastructure owner/operator	Road Operators should be developing plans for connecting ITS and Traffic equipment. Where possible, this should be via fiber optic cable to prepare for future applications.
Relevant national guidance/key decision makers	A federal executive order encourages use of highway right-of-way for shared use with telecommunications utilities. However, this is primarily a state and local issue. Decisions will be made locally about investment in broadband infrastructure or other communications methods as part of project scope.
Next steps	Road operators should develop clear strategy including identification of key routes and locations that will be most beneficial for broadband infrastructure. This should include looking at opportunities for partnerships and opportunities to collaborate with other initiatives such as the Rural Broadband Initiative.

Impacts Assessment to Prepare for Future Transportation System

Impact Area: Vehicle to Infrastructure Communication (V2I)	
Description	Connected vehicles use wireless communications systems to exchange messages with other vehicles and the driving environment. One application is vehicle-to-vehicle (V2V) communications: messages sent between vehicles. V2V communications are already being tested in pilots around the country and could have especially important applications for commercial vehicles. This assessment focuses on vehicle-to-infrastructure (V2I) communication, wireless communication between connected vehicles and digital systems linked to transportation infrastructure, usually through communication devices called roadside units installed near roadways. V2I communication can utilize dedicated short-range commutations (DSRC), cellular technology or sometimes Wi-Fi.[1] V2I technology can be used to communicate a wide range of information. Examples include advisories about approaching slowdowns, signal timing information, information about hazardous weather conditions and pedestrian detection. Many experts expect automated vehicles to also use connected vehicle technology. Vehicle-to-infrastructure communication could enhance automated vehicles' safety, especially in areas with variable rules of the road such as school zones, and improve the flow of traffic by integrating data about transportation infrastructure, traffic conditions and signal timing with automated driving system behavior.
Certainty/potential time horizon	V2I technology is already being deployed throughout the U.S., including in Oregon. The extent to which automated vehicles will integrate or require V2I features is highly uncertain.
Co-benefits/advancing established goals	V2I technology can provide safety benefits, improve the flow of traffic and provide more accurate and up-to-date information for the management of the transportation system through

[1] Connected Vehicle Impacts on Transportation Planning, Technical Memo #5: Case Studies, US DOT

	driver assistance features whether or not automated vehicles make use of the technology.
Barriers	In 2016, the National Highway Traffic Safety Administration (NHTSA) and U.S. DOT initiated the federal rulemaking process to mandate use of DSRC radios in all new light vehicles by 2023, but the current administration has delayed this process and taken a technology-neutral approach to regulation. This uncertainty about whether connected vehicle applications will rely on DSRC technology or 5G cellular technology has prevented both private companies and public agencies from investing in connected vehicle infrastructure. The FCC has reserved some of the 5.9 GHz band for DSRC vehicle safety applications. However, the FCC recently raised the possibility of opening up the 5.9 GHz band for use by unlicensed Wi-Fi networks, which makes the future of DSRC-enabled V2I applications more uncertain. The extent to which automated vehicles will integrate V2I technology is uncertain, and this will be a barrier to any development of that technology until there is a clearer picture of how these vehicles will operate. Most V2I messages do not broadcast individual- or vehicle-specific information, but concerns about protecting individual privacy would also need to be addressed. For more information about cybersecurity issues, see the Impact Assessment of Cybersecurity for V2I Communications.
Impact to infrastructure owner/operator	Costs will include installation and maintenance of connected vehicle infrastructure, as well as building the organizational capacity needed to establish, manage and maintain the system on an ongoing basis. The ability to receive messages from vehicles introduces new cybersecurity risks for agency systems and networks that need to be mitigated. V2I infrastructure will likely rely upon the broadband infrastructure and digital networks that underpin existing intelligent transportation systems infrastructure where present and may qualify for federal programs to aid ITS deployment.[2]

[2] Connected Vehicle Impacts on Transportation Planning, Technical Memo #5: Case Studies, USDOT

Relevant national guidance/key decision makers	The federal government has supported CV technology, but it has maintained a technology agnostic stance regarding DSRC and 5G, although the FCC has reserved some of the 5.9 GHz band for DSRC vehicle safety applications. The Cooperative Automated Transportation (CAT) coalition, a collaborative effort by the American Association of State Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE), and the Intelligent Transportation Society of America (ITS America), provides leadership and support for V2I technology deployment. The US DOT Intelligent Transportation Systems Joint Program Office is leading an effort called the Connected Vehicle Reference Implementation Architecture (CVIRA). The goal of CVIRA is to identify and encourage standards for connected vehicle technologies. The Federal Highway Administration (FHWA) has also released V2I resources and guidance: https://www.transportation.gov/briefing-room/fhwa0317
Next steps	Follow the progress of the federal connected vehicle pilot projects and benefit from the lessons learned on those projects. Monitor the National Operations Center of Excellence web site page for Connected and Automated vehicle resources for updated information and webinars on this topic. Evaluate locations for the deployment of V2I equipment, especially those where deployment can leverage existing ITS infrastructure, such as broadband connections and smart traffic signal controllers, to reduce cost. Invest in ITS systems that have the capacity to accommodate V2I equipment. Hire and develop a workforce with the technical expertise to maintain V2I equipment. Identify opportunities to pilot V2I technology to gain experience with V2I equipment and develop staff capabilities.

Impacts Assessment to Prepare for Future Transportation System

Impact Area: Cybersecurity for Vehicle to Infrastructure (V2I) Communications	
Description	Vehicle-to-infrastructure communication, or V2I, is the term for wireless communication between connected vehicles (CV) and digital systems linked to transportation infrastructure, usually through communication devices installed near roadways, called roadside units. Vehicle-to-infrastructure communication can utilize dedicated short-range commutations (DSRC), cellular technology or sometimes Wi-Fi.[1] Many experts expect automated vehicles to also use connected vehicle technology. V2I communication could enhance automated vehicle safety, especially in areas with variable rules of the road such as school zones or work zones, and improve the flow of traffic by integrating data about transportation infrastructure, traffic conditions and signal timing with automated driving system behavior. While emerging transportation technologies could help reduce crashes, congestion, and greenhouse gas emissions, increased utilization of advanced computing systems and software also increases the potential for cyberattacks. Cybersecurity breaches in a CV system could pose immediate safety risks and lead to crashes or other dangerous situations on the road. Because many of the regularly transmitted CV messages include speed and position data, this information could be used to track a specific user, violating the individual's privacy. In addition, cybersecurity breaches could undermine trust in CV systems; if drivers cannot trust information received through V2I messages, they will be less likely to take action based on those messages, diminishing the safety and efficiency benefits of CV technology. The U.S. Department of Transportation (US DOT) has identified four elements to securing connected vehicle systems, including vehicle cybersecurity, infrastructure cybersecurity, ITS architecture and standards security, and communications

[1] Connected Vehicle Impacts on Transportation Planning, Technical Memo #5: Case Studies, US DOT

	security.[2] The federal government has sole authority to establish cybersecurity standards for vehicles and equipment. This impact assessment examines communications security. As noted above, DSRC is not the only technology that can be utilized for V2I communications. However, most security research to date has focused on DSRC. In 2018, the Center for Transportation Research noted that DSRC is inherently resilient to some kinds of cyber based attacks. However, the same report notes that, similar to Wi-Fi, it can be susceptible to a wide range of attacks that could result in denial of service, loss of confidentiality, or degraded system integrity. The report acknowledges that more research is necessary to understand these attacks and design compensating measures.[3] While no single technology can provide security against all types of attacks, cryptographic systems will assuredly play a major role in ensuring the trustworthiness of V2I communications. To that end, the US DOT and partner organizations have created a proof-of-concept communications security system[4], called the Security Credential Management System (SCMS), designed to be used in federal CV pilots. The SCMS uses a public key infrastructure (PKI)-based authentication method to create, manage, distribute, use, store and revoke digital certificates. In the proof-of-concept project, the SCMS issues multiple digital certificates to users and constantly alters the certificates to preserve privacy. The certificates contain no information that could be used to identify individuals or pieces of equipment, but serve as system credentials so that other users can trust their messages. However, a full-scale deployment will require more research, investment and a business model that will sustain the SCMS over time. The US DOT has identified lessons learned and considerations for an SCMS deployment. Ongoing considerations include how on-board units (OBUs) can trust certificates from more than one authorized entity, the rules specifying how certificates are issued and retired over time, the manner in which certificates

[2] How the U.S. Department of Transportation Is Protecting The Connected Transportation System from Cyber Threats

[3] Cybersecurity Challenges and Pathways in the Context of Connected Vehicle Systems

[4] National Security Credential Management System – SCMS Baseline Summary Report, US DOT, January 2018

	are replaced, and the legal or policy framework which allows certificates to be revoked when bad actors are identified.[5]
Certainty/potential time horizon	V2I technology is already being tested, including in Oregon. The extent to which automated vehicles will be deployed with or will require V2I features is highly uncertain. Deployments of V2I technology will require cybersecurity systems.
Co-benefits/advancing established goals	To deploy V2I technology, the security of the communications has to be ensured. Securing V2I communications is essential to prevent attacks that, if successful, could lead to crashes and other dangerous road incidents. It is also essential to protect the privacy of individual users. Generally speaking, securing V2I communications is essential to prevent loss of trust in CV systems and ensure the full potential safety and traffic management benefits of CVs are realized.
Barriers	It is uncertain whether V2I communications will rely on DSRC or 5G technology, which has prevented both private companies and public agencies from investing in CV infrastructure. To date, published research regarding cybersecurity for V2I communications has focused on DSRC technology. It is also uncertain what level of government will have authority to implement and oversee the cybersecurity of V2I communications. For example, laws and regulations defining misbehavior that results in certificate revocation could be set by the federal government or by states and local governments. In either case, multiple departments and multiple levels of government will likely need to coordinate inspections and incident response and to enforce compliance with CV requirements. A full-scale, secure SCMS system would require an ownership and governance model that ensures effective governance and consistent funding. Otherwise, there could be issues with availability and inconsistent services, resulting in varying security, privacy and device standards across components and geographic areas. This could negatively impact interoperability, but it could also create vulnerabilities and expose the system to interference.[6]

[5] Full-Scale Security Credential Management System (SCMS) Deployment: Workshop Read Ahead
[6] Full-Scale Security Credential Management System (SCMS) Deployment: Workshop Read Ahead

	Depending on the ownership and governance model, industry competitors may need to participate in the system and would need to work together to ensure the system operates effectively and safely. One example is the payment card industry (PCI), in which competing companies (such as Visa and Mastercard) established a council to set privacy and security standards, run training programs, and annually certify adherence to the standards. Additional research is required to address some of the cybersecurity vulnerabilities of CV systems, especially vulnerabilities related to interference and confidentiality.
Impact to infrastructure owner/operator	State and local governments that operate network connected roadside infrastructure already have requirements for implementing security measures. The ability to receive messages from external entities such as a connected vehicle creates additional cybersecurity complexity. The federal government has taken primary responsibility for deploying a security credential management system for CV technology; although development of a system is proceeding slowly. State and local governments will need to implement SCMS technology for infrastructure points where V2I communications is enabled, but this is not possible until national standards and a sustainable business model are defined. Regulating and overseeing cybersecurity for the vehicle end of V2V or V2I communications will likely remain the responsibility of the federal government. However if federal standards don't develop fast enough to meet needs, state and local governments could be required to take an expanded role in securing V2I and V2V communications. Any state or local role in V2I communications security would require building organizational capacity, including hiring and training staff and investing in new systems. State and local agencies would also likely need to establish an ongoing source of funding for efforts related to V2I communications security because outdated CV communications technology could create cybersecurity risks. Contracts with companies with cybersecurity expertise may be required to audit systems and review agency cybersecurity procedures.

Relevant national guidance/key decision makers	The Intelligent Transportation Systems Joint Program Office (ITS JPO) and the National Highway Traffic Safety Administration (NHTSA) partnered with the automotive industry and security experts through the Crash Avoidance Metrics Partnership (CAMP) to create the SCMS proof-of-concept communications security system for connected vehicles pilots and other federally-funded V2X efforts. The goals for the SCMS project include defining a governance strategy for a full-scale SCMS, establishing an SCMS manager and hierarchy, and identifying roles and responsibilities for all the system participants.[7] Another research effort is the European Commission's Cooperative Intelligent Transportation System Trust Model concept. This concept envisions an infrastructure which provides redundancy and interoperability, allowing for more flexibility in expanding and decentralizing its operations. Initial next steps will include development of a working prototype at the European level. Work on design and implementation of the prototype have already begun.[8]
Next steps	Monitor US DOT's SCMS project for updates and observe AV pilots where the SCMS is used for lesson learned. Implementing CV infrastructure that is compliant with national standards that develop is important for achieving interoperability. Develop plans for hiring and developing a workforce with the technical expertise to design, deploy, and maintain V2I equipment and to monitor and mitigate cybersecurity risks.

[7] Full-Scale Security Credential Management System (SCMS) Deployment: Workshop Read Ahead
[8] European Commission: Intelligent Transportation Systems – Cooperative, Connected and Automated Mobility (CCAM)

Impacts Assessment to Prepare for Future Transportation System

Impact Area: Curb Space Management	
Description	By increasing demand for loading and unloading space and decreasing demand for parking, deployment of automated vehicles, especially in on-demand fleet applications, may necessitate changes to curb space management. Options for managing curbs to adapt to automated vehicles may include pricing, changes in zoning, reallocating curb space for different uses, geofencing curb spaces for certain activities, and the creation of dynamic curb spaces which have different uses at different times.
Certainty/potential time horizon	New technologies in transportation are already altering the demands on curb space. Transportation network companies (TNCs) and on-demand delivery services have increased the demand for loading and unloading areas to move both people and goods. Automated vehicles are expected to have similar effects as TNCs, since the first deployments of highly automated vehicles are likely to be in on-demand fleets.[1] While TNC drivers may stop in travel lanes or pick up passengers in areas not designed for that purpose, automated vehicles will be programmed to follow traffic laws and will need designated areas for passenger loading and unloading.[2] The effects of TNCs have already prompted cities and other jurisdiction to create new policies to manage their curb space.
Co-benefits/advancing established goals	Managing curb space to accommodate automated vehicles has the potential to further a number of goals such as:

[1] *San Francisco Curb Study*, Fehr&Peers/Uber Technologies
[2] *New Mobility in the Right of Way*, Urbanism Next Center, University of Oregon

	• Improving the flow of traffic and safety by moving pickup and drop-off areas out of the busiest travel lanes, and encouraging mode shift by allocating more space to transit and increasing the price of parking. • Accommodating the efficient delivery of goods by providing access to loading and unloading space, especially in dense areas. • Supporting transit and active transportation by making parking in city areas more limited and increasing the travel space available to transit services like buses and light rail. • Reducing harmful emissions by discouraging idling and circling and promoting turnover in loading and unloading areas. • Treating different users of the transportation system equitably by increasing the price of parking and using public space to the benefit of people other than car owners.
Barriers	Creating systems to effectively manage curb spaces first requires a good understanding of an area's curb space and their uses. Many infrastructure owner/operators do not have substantial or well-organized data about their curb spaces. Collecting this data, maintaining it and developing metrics to understand it will be a barrier. Private industry is addressing this gap by developing high definition map data. Some companies may provide access to this data as their business model, while others may collect data for their own purposes[3] To dynamically manage curb spaces, jurisdictions may need to obtain and analyze mobile phone data or deploy sensors.[4]

[3] *The Shared-Use City: Managing the Curb*, International Transport Forum Corporate Partnership Board
[4] *Curbside Management Practitioners Guide*, Institute of Transportation Engineers

	The time horizon, impacts and deployment models for automated vehicles are uncertain. While TNCs are commonly used as a proxy for AV behavior, AV impacts on the use of curb space will not be known until there is deployment at scale. Without further information, it will be difficult for infrastructure owners/operators to change curbside management practices or make investment in infrastructure updates to address the impacts of AVs. If the deployment of AVs increases loading and unloading activities, it could increase conflicts with bicyclists, who also travel alongside the curb and require safe and reliable access to that space. The needs of bicyclists must be considered when establishing new curb space management practices. Creating designated load and unloading zones or building more separated bicycle lanes could help reduce this potential conflict.
Impact to infrastructure owner/operator	Reallocating curb space could impact revenue, particularly in jurisdictions that rely heavily on parking revenue.[5] This lost revenue could be replaced by charging "curb-kiss" fees or other fees for vehicles using pickup and drop-off areas. For example, the District of Columbia has successfully implemented a paid permitting system to allow commercial vehicles access to loading zones at certain hours.[6]
Relevant national guidance/key decision makers	This area will largely be shaped by policy decisions made by local jurisdictions. Professional organizations such as the National Association of City Transportation Officials and the Institute of Transportation Engineers have released studies and reports on this topic.

[5] ibid
[6] ibid

	National guidance on vehicle to infrastructure communication protocol will be relevant for any efforts to use connected vehicle technology to administer dynamic curbside pricing.
Next steps	Examine state and city laws and regulations to understand the barriers to implementing new curbside management practices. Support efforts to gather and consolidate data about curbsides and their uses in local jurisdictions. Pursue data sharing agreements among public and private actors that possess data about curb space and the demands on it.

Impacts Assessment to Prepare for Future Transportation System

Impact Area: Electric Vehicle Charging	
Description	Electric vehicle charging infrastructure provides opportunities to charge electric vehicles. Charging is generally categorized by location (home, workplace, and public) and level, which indicates the voltage of the charger and therefore the speed with which a vehicle can charge (Level 1 is a standard 120V wall outlet; Level 2 is a 240V outlet of the type commonly used for residential dryers; Level 3 is a 480V charger developed specially for EVs). Homes and workplaces see higher demand for charging than public locations, and typically need lower levels of charging because vehicles are parker longer in these locations. Most AVs currently being developed are EVs, and many anticipate that deployment of AVs will increase the demand for EV charging.
Certainty/potential time horizon	Most AVs currently under development are EVs because EV drivetrains work better with AV control systems. However, it remains to be seen whether this will remain true as AVs continue to develop. The market for conventional-fuel vehicles is much larger than the market for EVs, which may drive AV manufacturers may move into developing conventional-fuel vehicles. Regardless of how AVs develop, the number of electric vehicles on the road is expected to increase significantly over the coming decades thanks to falling battery prices and increased ranges that make electric vehicles more useful. Some forecasts anticipate rapid growth in EV technology and usage over the coming decade. One analysis estimates that EVs, which are now significantly more expensive than comparable conventional-fuel vehicles, will cost the same as conventional vehicles by 2022.[1] Another analysis estimates that the average range of EVs will double between now and 2028.[2] These changes mean more EVs on the road, but they also call into question the value of some of the strategies that public agencies have traditionally used to support vehicle electrification. The subsidies that state and federal agencies offer EV buyers may no longer be necessary if the cost of EVs falls, and the public charging infrastructure that agencies often provide may not be needed if the

[1] https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost
[2] https://cleantechnica.com/2018/10/27/us-electric-car-range-will-average-275-miles-by-2022-400-miles-by-2028-new-research-part-1/

	range of EVs increases – or may fall out of date if even faster chargers are needed to support higher-range EVs. The question of whether public agencies should provide EV charging to prepare for AV deployment is complicated by the fact that AVs could be deployed in shared fleets rather than being individually owned. If so, it may be more appropriate for fleet operators to invest in EV charging infrastructure rather than for public agencies to make investments that primarily benefit private companies.
Co-benefits/advancing established goals	Providing EV charging could help to meet Oregon's climate goals as established in House Bill 3543,[3] as well as Executive Order 17-21,[4] which calls on the state to significantly increase the number of EVs on the road. However, there is no conclusive evidence that providing increased access charging outside the home makes a meaningful difference in increasing the number of EVs on the road.
Barriers	The main barriers to public investments in EV charging are high uncertainty (see above) and high costs (see below). In addition, several agencies in Oregon have been adopting more aggressive policies to make equity a guiding factor in transportation investments. This can make it harder to justify investment in EV charging since the EV owners are wealthier than average.[5]
Impact to infrastructure owner/operator	The cost of installing EV charging varies widely depending upon the location, site characteristics, and existing electrical infrastructure. Many residents can plug their EV into an existing garage outlet for free, whereas Level 2 chargers cost $6,000-9,000 per charger and Level 3 chargers cost $100,000-150,000 per charger, with costs tending toward the higher end of the range for public installations, which often involve complex sites without existing electrical infrastructure. Maintenance costs range from $300-2,000 per year.[6] Private companies typically operate charging stations at no additional costs to public agencies. There are currently no estimates of statewide EV charger needs for Oregon, which means that we cannot estimate the total costs of providing charging in the state.
Relevant national guidance/key decision makers	N/A
Next steps	Potential next steps include: • Amend the state building code to further require that new developments include charging or pre-wire parking areas,

[3] https://olis.leg.state.or.us/liz/2007R1/Downloads/MeasureDocument/HB3543
[4] https://www.oregon.gov/gov/Documents/executive_orders/eo_17-21.pdf
[5] https://www.usatoday.com/story/money/cars/2015/05/04/truecar-study-electric-cars-richer/26884511/
[6] https://www.greenbiz.com/blog/2014/05/07/rmi-whats-true-cost-ev-charging-stations

	which greatly reduces the cost of installing EV chargers in the future. The building code requires pre-wiring five percent of spaces in new parking facilities in Oregon's largest cities for EV charging,[7] and Executive Order 17-21 requires that the building code be amended by 2022 to require pre-wiring of at least one space in all new residential and commercial buildings, but there may be opportunities to further increase these requirements if projected demand for EVs increases. • Conduct an analysis of statewide EV charging needs, including under different AV deployment scenarios. • Dedicate additional funding, such as VW settlement funds or cap-and-invest revenues, to EV charging. • Continue or expand existing state EV charging initiatives, such as the West Coast Electric Highway. • Examine the impacts of increased EV adoption on electrical infrastructure to ensure that Oregon's power grid is able to accommodate increased number of EVs. • Continue to monitor adoption of EVs and other alternative-fueled vehicles.

[7] OAR 918-020-0380, https://secure.sos.state.or.us/oard/viewSingleRule.action;JSESSIONID_OARD=Xq-Xbj0797wOpb_J6CgYVS-0PCESzusfOx-I1-sILsE1sMPUoYlw!1747720130?ruleVrsnRsn=226334

Impacts Assessment to Prepare for Future Transportation System

Impact Area: Parking	
Description	It is possible that AVs will require less passenger vehicle parking than vehicles currently do. AVs may make it possible for travelers to send their vehicle back home or have it circle the block instead of finding and/or paying for a space in locations where parking is limited. It may be possible to park more vehicles using less space if AVs are able to navigate themselves into tighter spaces than human drivers. If AVs are operated in shared fleets, individual vehicle ownership could fall dramatically, significantly reducing the need for parking.
Certainty/potential time horizon	It is not clear whether or how much AVs will reduce the demand for parking, nor when these impacts will occur. Some of the factors creating uncertainty include: • AV deployment models: Much of the AV industry is focused on a shared-fleet deployment model that could reduce AV parking needs; ride-hailing services see the potential for AVs to cut the cost of service by eliminating labor costs, and AV companies such as Waymo are testing their AVs in shared service. However, it remains to be seen whether ride-hailing companies can successfully transition to a model where they own and operate large numbers of vehicles. • Response to shared services: Even if AVs are deployed in a shared-fleet model, it remains to be seen whether this model can succeed in the U.S. given the country's dispersed land-use patterns and long history of car ownership. Ride-hailing services, which essentially function as shared AVs with human drivers, have not yet produced a clear and significant impact on car ownership or parking demand. Lyft reported that 250,000 of its roughly 23 million users gave up a car in 2017,[1] but independent research has found that car ownership continues to grow in spite of ride-hailing, and that ride-hailing competes with public transportation more than it does with personal vehicles, which means that it could actually increase car ownership and parking demand.[2] • AV policies: if AVs circle or return home empty instead of parking at their destination it would significantly increase congestion and pollution. The public may want to manage or price AVs in a way limits that empty driving, which would limit one of the pathways by which AVs could reduce parking.Without changes to curb side management

[1] https://techcrunch.com/2018/01/16/lyft-says-nearly-250k-of-its-passengers-ditched-a-personal-car-in-2017/
[2] http://www.schallerconsult.com/rideservices/automobility.pdf

	practices, AV companies may also use public parking in busy downtowns as staging areas to be conveniently located for potential customers. • AV capability: the extent to which AVs allow for more space-efficient parking depends upon how accurately AVs are able to navigate. The impacts of AVs on parking will become apparent in high-demand locations when there are significant numbers of AVs on the road, and in other locations when the majority of vehicles on the road will be automated. Projections on AV adoption vary, but it seems likely that it will be 15 to 20 years before there are significant numbers of AVs on the road and at least 35 years until the majority of cars on the road are AVs,[3] potentially later given that many manufacturers and experts have been dialing back expectations around AV technology development.[4] However, the built environment is slow to change, and parking spaces that are being built today could last for 50 years. Even if AVs make it possible to reduce parking, it could be a long time before communities capitalize on the opportunity.
Co-benefits/advancing established goals	Though it is too early to tell exactly how much AVs will enable communities to reduce parking, there is a growing consensus that there is an overabundance of free and cheap parking in U.S. urban areas.[5] Changing parking policies and prices today would support several of Oregon's policy goals, including those that call for the state to support a variety of transportation modes (Statewide Planning Goal 12, Transportation Plan Goal 1), create sustainable communities (Statewide Planning Goal 13, Transportation Plan Goal 4), and create a variety of housing types (Statewide Planning Goal 10). Research has shown that creating compact communities, especially in urban centers and along major transportation corridors, is critical to meeting these goals,[6] and that reducing the amount and price of parking is critical to creating compact communities. Several of these goals explicitly mention the importance of increasing land use density in key locations. Denser communities create more opportunities for people to walk, bike, or take transit instead of driving; take shorter trips when they do drive; and live in a wider variety of housing types at a variety of price points. Local governments often require more parking in than is needed, which makes it harder to develop dense communities because it creates more space for cars instead of people

[3] https://www.vtpi.org/avip.pdf
[4] For example, see https://www.autonews.com/mobility-report/uber-sees-some-time-avs-dominate-road
[5] UCLA professor Donald Shoup has extensively documented the oversupply of parking and the potential of different parking reform policies. See https://www.shoupdogg.com/publications/.
[6] For a synthesis of the exhaustive literature linking dense, mixed-use communities to reductions in driving and increased use of other modes, see http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.710.1517&rep=rep1&type=pdf.

	and drives up the cost of development. The resulting oversupply of cheap parking also encourages people to drive even when other options are available. Furthermore, research on ride-hailing has found that one of the main reasons that people use ride-hailing is because parking at their destination is expensive or limited.[7] This suggests that implementing parking reform today instead of waiting for AVs to enable parking reform tomorrow could help to steer AVs toward a shared-fleet model that would better support Oregon's policy goals.
Barriers	Barriers to parking policy reform include: • The lack of transportation options in many communities. Unless people have other travel choices besides driving, increasing the cost or reducing the supply of parking may penalize drivers while failing to produce some of the benefits discussed above. The methods that are typically used to set parking requirements, which do not account for the extensive body of research showing how compact communities with good transportation options reduce the need for parking.
Impact to infrastructure owner/operator	Best-practice parking policy reforms typically increase revenues for infrastructure owner/operators. Increasing the cost of parking raises more revenue for agencies that manage parking infrastructure, and reducing parking supply or requirements typically enables higher-value development that contributes more tax revenue. There can be short-term costs associated with revising policies, redesigning streets, and installing new parking meters, but the long-term increase in revenue often allows agencies to recoup these costs relatively quickly.
Relevant national guidance/key decision makers	The Institute of Transportation Engineers' (ITE) *Parking Generation Manual*[8] is widely used to set parking requirements, but critics have argued that ITE does not account for the extensive body of research showing how compact communities with good transportation options reduce the need for parking, leading it to overestimate parking in demand in these locations.[9] Some agencies have adopted alternative methods to better estimate parking demand in urban areas.[10]

[7] For a summary of the research, see http://www.schallerconsult.com/rideservices/automobility.pdf.
[8] https://www.ite.org/technical-resources/topics/trip-and-parking-generation/
[9] For an overview of the concerns with ITE's approach, see http://shoup.bol.ucla.edu/TruthInTransportationPlanning.pdf. For an example of how ITE overestimates parking needs in urban settings, see https://nelsonnygaard.com/wp-content/uploads/2014/04/2014-01_Urban-Trip-Generation-Final-Report.pdf.
[10] For example, EPA has funded research and produced a tool to adjust parking demand estimates in compact, mixed-use areas (https://www.epa.gov/smartgrowth/mixed-use-trip-generation-model) and agencies like the City of Los Angeles (https://ladot.lacity.org/sites/g/files/wph266/f/VMT_Calculator_Documentation_20190228.pdf) have promoted the use of EPA's methods in development review.

	Developers, the lenders who finance them, and financial regulatory bodies all play an important role in implementing reduced parking requirements. Even where public policies encourage or require developers to provide less parking, lenders who look across their portfolios at average parking provision may view developments that meet these requirements as risky bets. Any extensive parking policy reform effort should include consultation with developers and lenders to ensure that the proposed changes are feasible to implement.
Next steps	AVs may or may not decrease parking demand, but there is plenty of evidence that many cities already have an oversupply of parking, and that reforming parking policy would help to achieve Oregon's policy goals. Local governments have authority over parking policies, and many are pursuing best practices including reducing or removing minimum parking requirements, increasing or managing the cost of public parking, and allowing for the shared use of existing parking rather than creation of new parking. State and regional governments can enact policies, issue guidance, and provide resources and tools to help implement this guidance. In particular, we recommend that the state strengthen existing policies and programs that support local parking policy reform, including: • Strengthening the current requirement in the Transportation Planning Rule that local governments in MPO areas implement parking plans that achieve a 10 percent reduction in the number of parking spaces per capita. • Requiring that planning projects funded by the state Transportation and Growth Management program address best practices that reduce the oversupply of parking. The TGM program has already funded development of several local parking policies, but grants do not require approaches to address parking reform. • Promoting parking cash-out programs, which allow employees to opt to receive cash instead of a parking space at work. State, regional and local governments can also take action to manage and price the transportation system in a way that encourages people to share vehicles, increasing the likelihood that AVs will be deployed in a model that supports the state's land use and transportation goals. Several agencies in Oregon, including ODOT, Metro, and the City of Portland are exploring pricing as a way to manage congestion and demand for driving. We recommend that agencies explore ways of implementing pricing that enable them to set higher prices for drive-alone (and in the future, zero- occupant) trips and trips in compact communities that already have good travel options. The State should also prioritize any AV funding or incentives for automated transit and shared AVs.

Impacts Assessment to Prepare for Future Transportation System

Impact Area: Lane Width	
Description	AVs could navigate more accurately than human drivers, which would mean that they could potentially travel in narrower lanes than human-driven vehicles currently do. We focus on narrowing lanes on highways and arterials, which currently have wider lanes than other streets to accommodate higher speeds, and present opportunities to narrow lanes under AVs.
Certainty/potential time horizon	Significantly reducing lane widths for passenger vehicles may be feasible when the majority of vehicles on the road are AVs that are proven to be able to navigate significantly more accurately than human drivers. It is not clear when the majority of vehicles on the road will be automated, but even according to more optimistic projections the majority of cars will be human-driven for the next several decades,1 and in the past year many manufacturers and experts have been further dialing back expectations of imminent Level 5 automation.2 Based on the limited AV testing being conducted today, it is not clear when, if ever, AVs will be capable of navigating roadways more accurately than human drivers – especially in adverse weather or difficult conditions.
Co-benefits/advancing established goals	Narrowing lane widths for passenger vehicles would support a variety of existing policy goals: • Oregon's statewide planning goals call for the state to support a variety of transportation modes (Goal 12), yet Oregonians still drive for most trips. Narrowing lanes could allow the state to create more space for transit and active transportation, making these modes safer and more convenient. • Goal 2 of the Oregon Transportation Plan calls for the state to improve the efficiency of the transportation system. Narrowing lanes could free up more space to create an extra lane and increase roadway capacity within the existing right of way. • Goal 5 of the Oregon Transportation Plan calls for the state to ensure that the transportation system is safe for all users. Research suggests that the 12-foot travel lanes that are standard on many highways and arterials encourage drivers to speed, and that narrowing lane widths on arterials reduces speeds without significantly reducing capacity or creating additional safety risks.[1] Therefore, narrowing travel lanes on

[1] For a summary of the relationship between lane widths and travel speeds, including citations of relevant research, see https://nacto.org/publication/urban-street-design-guide/street-design-elements/lane-width. FHWA

	certain arterials from 12 to 10 feet could produce immediate safety benefits even before AVs arrive, and AVs could then provide the potential to free up even more space in the roadway.
Barriers	Opportunities to reduce lane widths can be limited when roads serve multiple purposes. For example, passenger vehicles often share roadway space with commercial, freight and emergency vehicles that are typically wider than passenger vehicles and require wider lanes. A state highway that connects two different cities may become a main street for one of these cities. It is important to consider all road users and purposes before narrowing lanes. Looking ahead, additional barriers to changing passenger vehicle lane widths are the high uncertainty (see above), high costs (see below), and potentially lack of data. Data on AV volumes and travel patterns is essential to determining when and where infrastructure owners can narrow lanes and how they might redesign roads. Many proposed state and federal AV policies have not provided for the sharing of this data with infrastructure owners.
Impact to infrastructure owner/operator	According to one DOT, restriping costs run roughly $1.14-1.37 per linear foot, or $12,000-14,500 per lane-mile.[2] However, restriping is less expensive than widening a roadway, so restriping can save infrastructure owners money if it enables more lanes to fit in the same overall right of way. In addition, if automated vehicles waver less within the narrowed lanes, it could increase rutting, which would also increase maintenance costs over time.
Relevant national guidance/key decision makers	AASHTO's *Policy on Geometric Design of Highways and Streets* ("The Green Book")[3] is the set of roadway design standards most commonly used by infrastructure owners, particularly state and county agencies. The Green Book currently allows for lane widths as low as 10 feet on arterial street, but would need to be amended (or states would need to adopt separate design guidance) to allow for lanes narrower than 10 feet. The NACTO Urban Street Design Guide,[4] which is used in lieu of the Green Book in many larger cities, calls more explicitly for lanes to be narrower wherever feasible.
Next steps	Due to the fact that AV technology is still developing and the many different uses that many roadways serve, it will likely be several decades before infrastructure owners can begin to consider narrowing roadways to take advantage of AVs. Potential next steps include:

acknowledges the relationship between lane widths and vehicle speeds, and recommends reduced lane widths as a strategy to improve safety in reduced-speed urban environments: https://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/chapter3/3_lanewidth.cfm.

[2] http://www.virginiadot.org/projects/resources/NorthernVirginia/AppendixL_PlanningLevelCostEstimate.pdf

[3] https://store.transportation.org/item/collectiondetail/180?AspxAutoDetectCookieSupport=1

[4] https://nacto.org/publication/urban-street-design-guide/

	• Creating guidance describing the conditions (AV saturation, maturity) under which the state may want to consider restriping AV lanes • Adopting policies governing reallocation of new space created by AVs