RUC WEST

Road Usage Charge/Automated Vehicle Demonstration Project Report

FINAL

November 29, 2021

RUC west

ACKNOWLEDGMENTS

We appreciate the Western Road Usage Charge Consortium (RUC West) for choosing CDM Smith's Collective Impact Team to conduct this comprehensive assessment. We thank the following teams, who provided input, feedback, and guidance throughout this process.

RUC WEST PROJECT TEAM

- Oregon Department of Transportation – Lead Agency
- California Department of Transportation
- Hawaii Department of Transportation
- Idaho Department of Transportation
- Nevada Department of Transportation
- Oklahoma Department of Transportation

CONSULTANT TEAM

- CDM Smith (formerly Milestone Solutions) – Prime Consultant
- Jacobs
- Teague

SUBJECT MATTER EXPERTS

- AECOM
- JMC Rota
- Gannett Fleming

PROJECT PARTNERS

- Azuga
- Udelv

SPECIAL THANKS

- Udelv
- CAVnue LLC
- Participating automotive vehicle manufacturers
- Perrone Robotics
- Sidewalk Infrastructure Partners
- EROAD

Oregon
Kate Brown, Governor

Department of Transportation
Office of Innovative Funding
355 Capitol St NE, MS 32
Salem, OR 97301

November 16, 2021

Roshini Durand
CDM Smith
14432 SE Eastgate Way
Bellevue, WA 98007

Dear Ms. Durand,

I appreciate the time and energy that went into the RUC West AV-RUC Demonstration Project. The expertise of the consulting team and participants summarized in this report will help Oregon chart its course as it contines to refine its existing road usage charge program, known as OReGO. I also want to acknowledge the participation of other RUC West states.

The cooperation between participating states is key to RUC West success. Not all RUC West states have determined that a road usage charge program is the answer to impending transportation funding issues, but that does not stop the collaboration between states. RUC West states can participate in research that most benefits them, such as examining the impact of a RUC system on their rural and urban populations. But even non-participating states can benefit from research like this, which provides insights into how industry is thinking about such a program and the impacts on that industry.

Sincerely,

Maureen Bock
Chief Innovation Officer

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Terminology

Automated vs. Autonomous

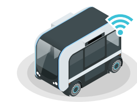
The terms "**automated**" and "**automation**" describe when a machine does all or some of the work of a person. The term "autonomous" describes when something or someone operates independently of human interaction. Both terms describe vehicles that operate with machine assistance/full operation of driver tasks. The United States Department of Transportation, federal legislation, infrastructure operators and owners, and educational institutions generally use the traditionally correct "automated," while industry uses the term "autonomous."

AV Vendor, OEM, and CAMs

An **AV vendor** refers to companies that provide the automating intelligence of automated vehicles (AVs) (sensors, processors). Such firms include Udelv, Waymo, and Cruise.

Automakers or original equipment manufacturers (**OEMs**) manufacture the vehicles.

Commercial account managers (**CAMs**) are private entities that process the data, compute road usage charges (RUC) owed, distribute invoices, collect revenue, and manage user accounts.



Connected Vehicles

Direct (DSRC/CV2X/V2X)[1] – Direct short-range radiocommunications (DSRC) are very low latency and can be used for safety and tolling applications. Messages are sent over direct communications many times per second. Currently, there is a 30-megahertz (MHz) spectrum space around 5.9 gigahertz (GHz) allocated by the Federal Communications Commission (FCC) for direct communications. Current language from the FCC limits the use of that frequency allocation to safety applications.

Telematics/V2N – Telematics data are transmitted directly from a vehicle over an existing telecommunications mobile network, such as those owned by Verizon or AT&T. Many new vehicles send data about themselves over such networks back to the OEM. Telematics data are not currently used for tolling but may be used to support RUC and tolling in the future.

[1] V2X stands for "vehicle to everything" communications. There are several components of V2X, including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) communications.

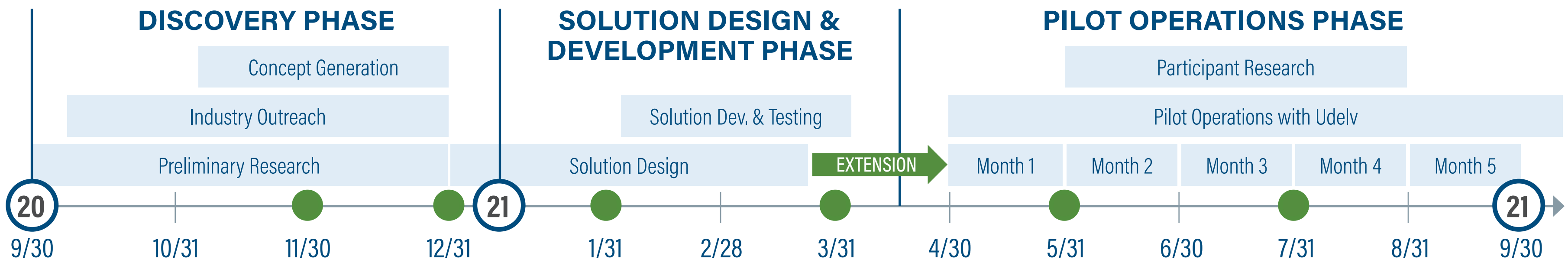
Acronyms

ADAS	Automated Driving Assistance Systems
ADV	Autonomous Delivery Van
API	Application Programming Interface
AV	Automated Vehicle
CAFE	Corporate Average Fuel Economy
CAM	Commercial Account Manager
CAV	Connected and Automated Vehicle
ConOps	Concept of Operations
CV	Connected Vehicle
CV2X	Cellular Vehicle-to-Everything
DLT	Distributed Ledger Technology
DOT	Department of Transportation
EV	Electric Vehicle
FHWA	Federal Highway Administration
GNSS	Global Navigation Satellite System
ICD	Interface Control Document
ICE	Internal Combustion Engine
LiDAR	Light Detection and Ranging
MPG	Miles per Gallon
MPGe	Miles per Gallon Equivalent
MVP	Minimum Viable Product
OBU	Onboard Unit
OEM	Original Equipment Manufacturer
OTA	Over-the-Air
RADAR	Radio Detection and Ranging
RUC	Road Usage Charge
SAE	Society of Automotive Engineers
SIP	Sidewalk Innovation Partners
SRS	System Requirements Specifications
STSFA	Surface Transportation System Funding Alternatives
UX	User Experience
VIN	Vehicle Identification Number

EXECUTIVE SUMMARY

With the increasing pace of development and deployment of automated vehicles (AVs), the Western Road Usage Charge Consortium (RUC West) recognized that any long-term RUC solutions must consider the emergence of AVs. A RUC West project team led by the Oregon Department of Transportation (DOT), and including California, Hawaii, Idaho, Nevada, and Oklahoma DOTs, initiated the RUC/AV Demonstration Project to explore the technical feasibility and unique issues and opportunities that exist in applying a RUC to AVs. The overall vision for the RUC/AV Demonstration Project is to gain an understanding of how AVs may interface with RUC systems by identifying what opportunities exist to leverage existing technologies within AV implementations to facilitate the RUC to AV interface, and to overcome implementation challenges to increase acceptance.

As lead consultant for the RUC/AV Demonstration Project, CDM Smith assembled the Collective Impact Team, comprising team members from Jacobs, Azuga, and Teague, as well as subject matter experts from AECOM, JMC Rota, and Gannett Fleming. CDM Smith partnered with Udelv to participate as an AV vendor to demonstrate technical feasibility of charging RUC to AVs through an automated and direct data exchange with the RUC platform provided by Azuga. In addition to Udelv, CDM Smith recruited a variety of stakeholders from distinct industry segments, including automotive and heavy vehicle manufacturers, delivery service providers, AV technology suppliers, and digital innovation partners to provide input on their technologies and business models.



CDM Smith's Collective Impact approach was a response to the diversity of AV stakeholders, the rapidly changing connected and automated vehicle (CAV) landscape, and AV ownership and manufacturing models that might become dominant. The team organized the project into the following three main phases—discovery, design and development, and pilot operations—over the course of 12 months:

- **The discovery phase** comprised industry outreach, preliminary research, and concept generation activities. This phase lasted three months and resulted in a RUC/AV pilot concept used to demonstrate the data exchange between Udelv's AV platform and Azuga's RUC platform. Besides the pilot concept, the Collective Impact Team generated forward-looking concepts that would inform mobility policy goals related to AVs.
- **The design and development phase** comprised solution design, development, and testing activities over four months. The RUC/AV pilot concept was refined and developed into a pilot system that was tested with Azuga's RUC platform using Udelv's data reporting capabilities.
- **The pilot operations phase** included data reporting and participant research activities. Udelv enrolled its Level 4 AVs in the pilot and exchanged data between its AV platform and the RUC platform for five months through two data exchange interfaces (a granular data exchange per trip per vehicle and a monthly data exchange per vehicle per pricing zone). Azuga distributed monthly statements to Udelv and provided the raw data for both data exchanges, which were summarized in monthly reports to RUC West. Over the course of the pilot, the AVs reported more than 55,000 miles, for which different RUC rates were applied across simulated pricing zones representing Oregon, Washington, and Utah. Pilot operations concluded with participant research activities featuring Udelv and additional fleet operators to enhance the pilot perspectives.

Pilot operations validated the technical feasibility of exchanging RUC data between a RUC platform and an AV Level 4 vehicle platform. Based on the data generated during pilot operations, the team concluded that the granular data exchange per trip per vehicle was reliable and accurate. However, the pilot data did not confirm the ability of an independent AV fleet operator to act as a trusted source and aggregate data on their vehicle platform for RUC purposes. It may be possible for an AV fleet operator to act as an aggregation source, but it would be necessary for an independent body to verify or certify the AV fleet operator's aggregation calculations as a trusted source for that approach to be feasible. Unless an AV fleet operator is verified to offer data aggregation as a trusted source, a separate certified Commercial Account Manager (CAM) will be needed to provide RUC data in the appropriate format and collect payments for vehicles subject to RUC.

Through research and stakeholder engagements, the team worked to capture technology trends and the diversity of the AV world to ensure recommendations would be vendor-agnostic and mindful of the constraints borne by businesses operating AVs.

This research effort also includes some potential next steps for RUC West to explore other opportunities to use technology and involve AV stakeholders further. The Collective Impact Team developed forward-looking RUC scenarios, or Northstar concepts, that could inform RUC policy in the next five to 10 years. These ideas are based on best estimates of where technology, industry/business, and government are heading from the latest information available to the team. These include concepts in which:

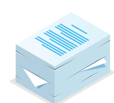
- AV fleet owners could share data and potentially benefit from reduced RUC rates.
- OEMs could support more RUC data processing activities to address privacy concerns and help reduce cost of collection.
- States could eventually use distributed ledger technology for RUC.

Key takeaways from the Collective Impact Team's research include the needs for states to:


Work with standards bodies such as OmniAir and the Society of Automotive Engineers (SAE) to create explicit RUC data standards and engage with AV stakeholders at the highest level in the manufacturing order as possible (i.e., original equipment manufacturers [OEMs]) to define RUC collection and payment standards.


Prioritize establishing standards for RUC data collection from connected vehicles (CV) as rapidly as feasible, so players in the CV ecosystem are prepared to provide these data as RUC systems become operational. Vehicles capable of partially automated operation will all be CVs, and connectivity will be the most important enabler for RUC in the next five years at least.

Explore opportunities to leverage AV technology in the development of a standardized RUC software module. Such a module could be integrated to AV platforms to achieve trusted source certification in a simple and cost-effective manner.


Avoid making assumptions about the capabilities or resources an AV business might have to accommodate standardization and accurate reporting through built-in telematics systems. Understand the diversity of AV fleet businesses before imposing a RUC solution. Continue supporting different mileage reporting choices to minimize burden on fleets, and give options to protect commercially sensitive information.


Seek opportunities to eliminate redundancy with other taxes by looking for policy synergies, prioritizing interstate operability, and establishing a single set of RUC rules across states.[2]


Continue engaging with AV stakeholders (and new transport and mobility players in general) to raise awareness on RUC and clear any misperception that RUC might target AVs specifically.

[2] This recommendation is generally applicable to all types of vehicles, but it is particularly relevant for AV businesses that are likely to operate in constrained regulatory environments.

INTRODUCTION

For decades, fuel tax revenues have supplied the majority of funds for roadway projects within the United States. However, increasing fuel efficiencies in automobile fleets, combined with the growing popularity of electric vehicles, are resulting in a collective decrease in fuel tax revenues. A road usage charge (RUC) is a viable alternative to fuel taxation in the United States. Oregon and Utah have implemented RUC, and other states and the federal government are exploring it further.

The Western Road Usage Charge Consortium (RUC West) and its member states are leading the way for the rest of the nation by investigating and testing user-based alternative revenue mechanisms. Anticipating the impacts automated vehicles (AVs) may have on transportation funding, a RUC West project team led by the Oregon Department of Transportation (DOT), and including California, Hawaii, Idaho, Nevada, and Oklahoma DOTs, initiated the RUC/AV Demonstration Project to explore the technical feasibility of applying a RUC to AVs.

As the project explores the premise that AVs are expected to have wide-ranging impacts on many aspects of the transportation system, including transportation funding, RUC West member states acknowledged that no mechanism has yet been implemented to charge these potentially highly fuel-efficient or electric AVs fairly and efficiently for their road usage. RUC West decided there is value in establishing data sharing and reporting requirements necessary for AVs to implement a RUC while AVs are being deployed on a trial basis and RUC programs are still evolving.

RUC West, therefore, sought to partner with the private sector to demonstrate the feasibility of applying a RUC to AVs through a functional, combined AV and RUC implementation, as well as validate data sharing between AV telemetry Level 3 or higher and existing RUC systems. A complementary objective of this demonstration was to address technological and administrative considerations that might inform further system development and policy.

The final report is organized in five sections:

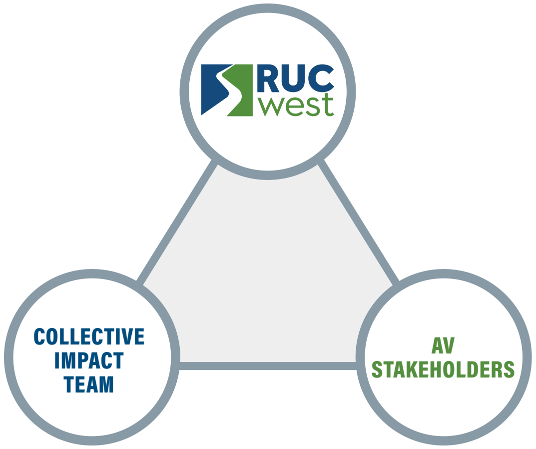
SECTION 1 presents the key actors involved in the project and the background to the RUC project.

SECTION 2 covers the project goals, objectives, and methodology. It also introduces key insights gathered during the project that informed the pilot concept, forward-looking RUC/AV concepts, and recommendations.

SECTION 3 presents key pilot and participant research findings from the pilot and recommendations to establish open standards, increase convenience and user acceptance, and find efficiencies to reduce cost of collection.

SECTION 4 presents the potential future of AVs and RUC as the AV landscape evolves and impacts ownership models. It includes recommendations for using AV's technical capacity to support other mobility policies in addition to RUC.

SECTION 5 offers opportunity areas for further exploration as policymakers seek to leverage advancements in AV technology.



RUC West launched a competitive bid process in April 2020 and contracted CDM Smith[3] to deliver the RUC/AV Demonstration Project. CDM Smith assembled the Collective Impact Team, comprising team members from Jacobs, Azuga, and Teague, as well as subject matter experts from AECOM, JMC Rota, and Gannett Fleming.

The Collective Impact Team engaged with AV stakeholders from distinct industry segments, including automotive and heavy vehicle manufacturers, delivery service providers (Udelv), AV technology suppliers (Perrone Robotics), and digital innovation partners (Sidewalk Innovation Partners [SIP]) and CAVnue LLC [CAVnue]). The project featured Udelv as the AV vendor contracted to participate in the RUC/AV pilot to demonstrate feasibility. It also extended research to include a variety of fleet operators to enrich perspectives on fleet operational needs beyond Udelv's.

[3] RUC West contracted with Milestone Solutions in September 2020. Milestone Solutions was subsequently acquired by CDM Smith in June 2021.

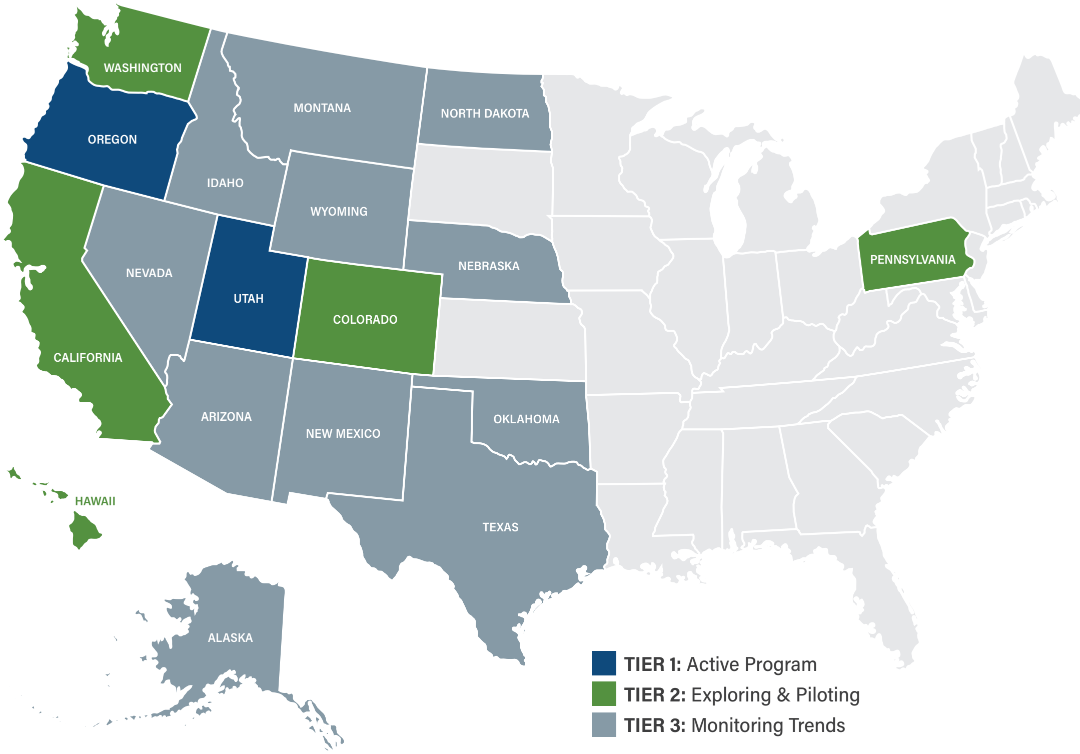


Figure 1: RUC West States

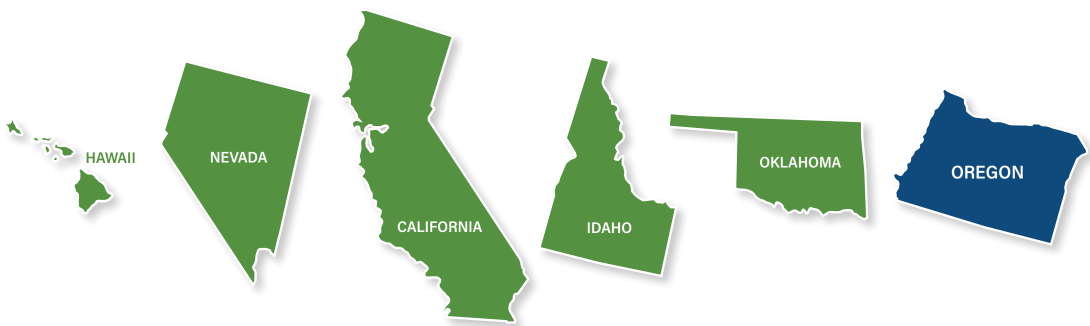


Figure 2: RUC West States Participating in the RUC/AV Demonstration Project

1.1 Key Actors Involved

The key actors involved in this project include RUC West, which commissioned this RUC/AV Demonstration Project; the Collective Impact Team, who led the study and implemented the pilot operations; the AV vendor (Udelv), who participated in the pilot operations to demonstrate feasibility of the RUC/AV data exchange concept; and the AV stakeholders, who were consulted throughout the pilot to provide insights on technology advancements and AV business models and operations.

1.1.1 RUC West Project Team

RUC West is a voluntary coalition of 18 state DOTs that are committed to collaborative research and development of a new method for funding transportation infrastructure based on drivers' actual road usage (see Figure 1 for a map of RUC West states). Its main goal is to build public-sector organizational capacity for, and expertise in, RUC systems and the associated policy, administrative, and technology issues. RUC West provides a collaborative forum to share information and best practices, discuss issues, observe and learn from other public agencies that are at different stages of testing and implementation, and facilitate joint research, thereby achieving economies of scale. RUC West and its member states are paving the way for the rest of the nation by investigating and testing user-based alternative revenue mechanisms. The RUC West project team was led by the Oregon DOT, and included California, Hawaii, Idaho, Nevada, and Oklahoma State DOTs (Figure 2).

1.1.2 Collective Impact Team

CDM Smith assembled a core team of experts from Jacobs, Azuga, and Teague to lead the RUC/AV Demonstration Project, supporting RUC West in all facets of the project. This team comprised subject matter experts from AECOM, Jacobs, and JMC Rota, who offered their pointed expertise on connected and automated vehicle (CAV) technology and standards development, which allowed the team to gain a better understanding of the AV landscape and research initiatives underway (Figure 3).

CDM Smith was the prime contractor and joined forces with Jacobs as its main delivery partner to bring in key RUC expertise required for this project. Azuga brought its technical expertise and a RUC platform that was optimized to demonstrate feasibility of data exchange between AVs and a RUC system. Teague leveraged its user-experience design expertise to lead concept generation and participant research activities. Teague also offered insights into some of the latest user experience research initiatives in which AV businesses and original equipment manufacturers (OEMs) are engaged.

CDM Smith advised on RUC policy, determined project approach and system design to support policy and research objectives, and coordinated subject matter experts. Subject matter experts from AECOM, Jacobs, and JMC Rota brought their experience working on CAV projects across the United States to the following areas:

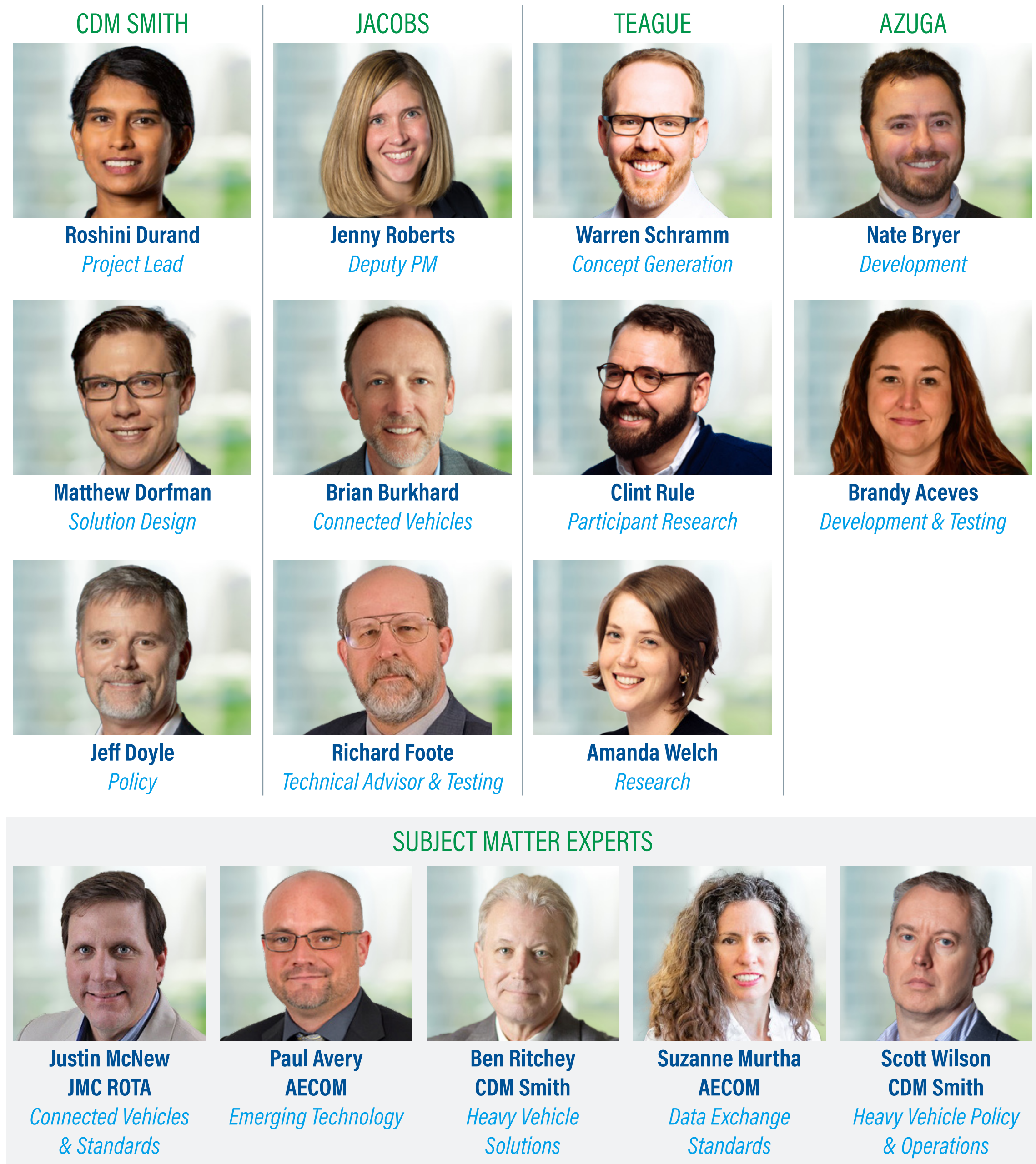


Figure 3: Collective Impact Team

- Jacobs managed testing and pilot operations and documented the state of play of AV research in the United States.
- AECOM and JMC Rota experts provided insights on vehicle communication standards and vehicle technologies, as well as advised on standards for a RUC/AV implementation.

In addition, Gannett Fleming offered updates on two AV research initiatives conducted at the federal level.

The Collective Impact Team's responsibilities for the RUC/AV Demonstration Project included:

- Engaging with the AV vendor and AV stakeholders to introduce key RUC concepts and learn about their capabilities and constraints
- Designing, developing, and testing the pilot solution with the AV vendor
- Conducting participant research with Udelv to understand AV fleet operational and business constraints
- Participating in co-creation activities to generate RUC/AV concepts to be piloted and forward-looking concepts to be further researched
- Managing pilot operations, as well as reporting pilot data and pilot activity to RUC West
- Identifying opportunity areas to inform RUC policy design
- Designing the RUC/AV pilot approach and establishing key success metrics
- Collecting and analyzing data throughout the pilot to validate reliability and accuracy of the RUC/AV concept
- Advising on leveraging RUC/AV standards and emerging technologies

1.1.3 Automated Vehicle Vendor

The Collective Impact Team recruited Udelv to participate as an AV vendor operating AVs with telemetry Level 3 or higher to demonstrate feasibility of the data exchange with a RUC platform. This key requirement of the RUC/AV Demonstration Project provided invaluable insights into the real business challenges facing AV fleets, in particular those operating in the high-tech world.

Udelv is an autonomous delivery van (ADV) company based in Burlingame, California. Its mission is "to improve people's lives by making delivery cheaper, cleaner, and safer." Udelv's ADVs are built specifically for driverless last- and middle-mile delivery on public roads.

As with many high-tech startups, Udelv operates in a fast-paced business and technical environment and has experienced significant changes since its inception in 2018. Udelv launched its first-generation Level 4 AV in January 2018, with which it achieved 1,400 deliveries over the course of that year.

The company developed its second-generation AVs on the base of a Ford Transit Connect chassis in 2019 (Figure 4). This upgrade allowed Udelv to increase its vehicles' speed and range and improve the arrangement of the cargo space. At the time the pilot launched, Udelv was operating Level 4, light-duty delivery vehicles in three RUC West states (Arizona, California, and Texas). From 2019 to the beginning of 2021, Udelv had fulfilled nearly 30,000 deliveries for multiple merchants in California, Arizona, and Texas, and was planning for expansion in other states.

By the end of the pilot, Udelv had announced its strategic partnership with Mobileye to develop enhanced 3D mapping capabilities for its fully electric, third-generation vehicles (Figure 5), to achieve its goal to scale automated delivery operations further and become a major logistics player.[4]

Figure 4: Second-Generation Automated Vehicles

Figure 5: Third-Generation Vehicles Powered by Mobileye's Self-Driving Technology

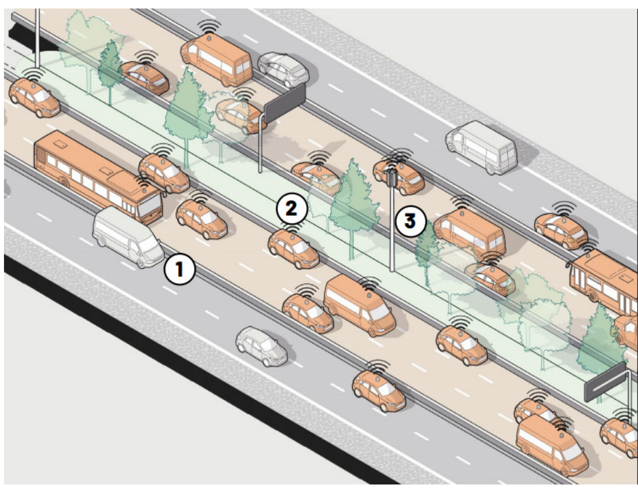
[4] Intel. 2021. "Mobileye and Udelv Ink Deal for Autonomous Delivery." Accessed November 18, 2021, https://www.intel.com/content/www/us/en/newsroom/news/mobileye-udelv-deal-autonomous-delivery.html#gs.eej9cm.

1.1.4 Automated Vehicle Stakeholders

With the understanding that AVs operate with diverse technologies and business models that are still evolving, it was critical for the Collective Impact Team to avoid getting locked into proprietary or limited technologies or system designs that only serve a selected segment of the industry at a specific point in time.

In addition to Udelv, the Collective Impact Team engaged with the following AV stakeholders and invited them to provide their insights throughout the project:

- **Perrone Robotics is an AV supplier with a digital autonomous engine for AV data abstraction.** It is currently testing its Level 4 autonomous shuttle, "Tony." Given its expertise in retrofitting regular vehicles into Level 4 AVs through the provision of hardware and software packages for a wide variety of businesses, Perrone Robotics was also solicited for a technical advisory role. Experts from Perrone Robotics participated in technical workshops along with subject matter experts to provide input on the technical design of the RUC/AV pilot solution.
- **CAVnue.** Its mission is "to pioneer the future of roads and related technology for a more connected and autonomous mobility future." As a technology vendor contracted to design and operate a CAV technology stack on the Michigan CAV corridor project (Figure 6), the Collective Impact Team invited CAVnue to provide insights on the digital technology roadmap that could support future mobility pricing needs.[5]
- **Automotive Vehicle Manufacturers.** The Collective Impact Team invited an automotive vehicle manufacturer pursuing leadership positions in CAV services, and a medium/heavy commercial vehicle manufacturer investing in AV technology to provide their perspectives as AV stakeholders. These companies provided insights on how their vehicle technologies could be enabled to help decrease cost of RUC collection, simplify mileage reporting, and increase convenience for their end users.



Highway

1. PHYSICAL INFRASTRUCTURE

Well-maintained roadways
Seperation barriers to ensure efficiency and safety
Enhanced, machine-readable markings, digital signage and signaling
Enhanced maintenance to maximize pavement life, including levels of prediction and automation

2. DIGITAL INFRASTRUCTURE

Ubiquitous, highly reliable connectivity
High-definition ("HD") images
High accuracy ground-based GPS
Road sensors for traffic, weather, road conditions

3. COORDINATION INFRASTRUCTURE

System to manage vehicle coordination and interoperability
Ability for transportation authorities to set policy goals for maximize mobility and accessibility, and track their impact

Figure 6: CAVnue to Create Corridor for Connected & Automated Vehicles in Michigan

[5] Michigan Department of Transportation. "Connected and Automated Vehicles (CAV) Corridor." Accessed November 18, 2021, https://www.michigan.gov/mdot/0,4616,7-151-9621_101547---,00.html.

1.2 Background on the Project

For nearly a century, the motor fuels tax (or gas tax) has provided the vast majority of funding for the United States' extensive network of highways and local roadways. The motor fuels tax provided a stable and generally sufficient amount of revenue for the initial establishment, upkeep, and repair of highways and roadways for many decades due to its low collection cost. Not only was it stable, but it was deemed reasonably equitable to motorists, because each driver paid in general proportion to his or her actual roadway use. Prior to the establishment of the fuel tax, property taxes, registration fees, and even conscripted labor through a statutory road labor assessment levied by local governments fund the roadways;[6] there was no usage-based method of paying for roads other than a very limited number of local toll roads.

From the 1920s to the 1970s, passenger vehicles generally consumed fuel at approximately the same rate, regardless of the vehicle make, model, or year. As a result, all drivers paid about the same amount of gas tax per mile traveled, regardless of passenger vehicle type. The 1973 Yom Kippur War in the Middle East and the resulting oil crisis spurred the U.S. government to enact for the first time Corporate Average Fuel Economy (CAFE) standards. Automakers responded by improving vehicle fuel efficiency, resulting in average new vehicle miles per gallon (MPG) increasing from 13.5 MPG in 1975 to 27.5 MPG by 1985. The government has continued to implement adjustments to CAFE standards, and automakers once again increased MPG outputs after 2004, with improvements continuing ever since. With an increasing mix of advanced technology vehicles (stop-start engines, hybrid engines, EVs, etc.), there is now a wide range of light-duty vehicle MPG represented in the overall vehicle fleet. New, advanced technology vehicles can achieve an MPG (or miles per gallon equivalent [MPGe]) of 50 MPG to over 150 MPGe. Meanwhile, regular gas-powered vehicles (including older vehicles), SUVs, and pickup trucks have modest fuel economy ratings of 12 to 30 MPG, depending on the type of vehicle.

1.2.1 Current Road Usage Charge Initiatives in the United States

As vehicles and the fuels that power them evolve, the method of paying for roadways must also evolve from the current reliance on fuel taxes to fund roadway maintenance and improvements. RUC (a distance-based tax) is being examined at both the state and federal levels as a possible future replacement for the gas tax. Some states have already begun this transition, starting with Oregon in 2015 and Utah in 2020. States with enacted programs offer RUC as an alternative to vehicle

[6] Dearing, Charles L. 1941. "American Highway Policy," *American Journal of Agricultural Economics* 103, no. 5 (October): 42-43. [https://doi.org/10.2307/1231978]

registration surcharges on EVs. Virginia will have a voluntary RUC program in place in 2022, which will include EVs and highly fuel-efficient vehicles defined as vehicles with an average MPG greater than 25. Several other states are designing and testing potential RUC systems, as illustrated in Figure 7. For its part, the federal government created the Surface Transportation System Funding Alternatives (STSFA) program, which provides competitive grant funding to states to explore alternative funding approaches for transportation. Almost all of the federal grants awarded under the STSFA program have been for state or multistate-level exploration of mileage-based fees (also known as RUC). The STSFA grant program partially funds the RUC/AV Demonstration Project.

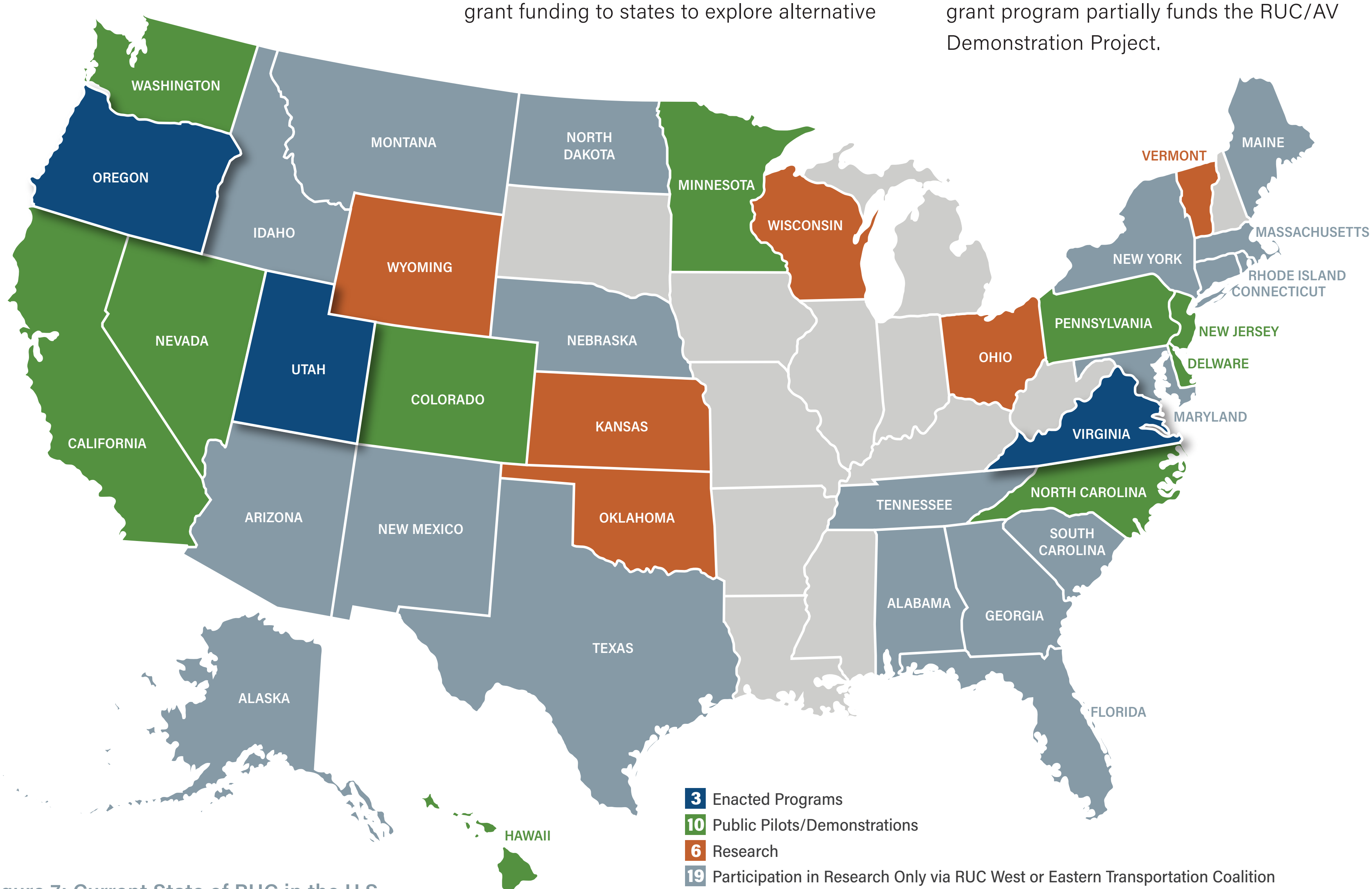


Figure 7: Current State of RUC in the U.S.

1.2.2 Anticipating Automated Vehicle and Road Usage Charge Interaction

Automakers and, more recently, new entrants into the automotive industry have increased investments in advanced technology, including the first generation of AVs. It is widely believed that AVs will be mostly EVs powered from large onboard batteries that are charged from the power grid.[7] The prospect of a growing fleet of EVs operating with some level of autonomy raises two important issues for policymakers that this project intends to address:

> ?
>
> How will roadway maintenance and needed improvements be funded in the future given such vehicles will not be subject to gas taxes?

> ?
>
> What changes in travel patterns and roadway usage can be expected if vehicles become fully automated for goods movement, passenger movement, or both?

1.2.2.1 Advancement in Automated Vehicle Technology

Research continues to propel the advancement of AVs toward commercialization. Nearly every OEM has claimed to have a commercially available, highly automated vehicle within the next five years. OEMs claim that these features will fall into the SAE Level 3 or higher level of automation (Figure 8).

OEMs previously invested heavily in AV-sensing components like LiDAR, RADAR, and ultrasonic LiDAR technology, as well as high-definition cameras coupled with video analytic technology, allowing for real-time object identification, recognition, and warning issuance as a means of driver assistance. With these systems fully integrated into commercially available vehicles, OEMs are pivoting their investments for AVs toward vision-based machine learning and artificial intelligence. These systems are being developed to support machine learning engines that can allow vehicles to be operated with automated driving features identified in SAE Level 3 or higher classifications.

The federal government continues to support research and development in the advancement of AVs. Projects like the Federal Highway Administration (FHWA) Roadway Automation Concept of Operations and FHWA AV Infrastructure Readiness are evaluating scenarios regarding how AVs might evolve and what the government should be prepared for. These and other efforts are creating the necessary dialogue to engage OEMs and governments in a collaborative approach to develop test corridors, readiness planning, system evaluations, regulation, policy, and strategy planning.

As an example, the latest update to the *Manual on Uniform Traffic Control Devices*[8] contains a new section, "Part 5 – Automated Vehicles." This informative chapter provides guidance on minimum signing, striping, and signaling requirements to help AVs operate on roadways. Informed by a consortium of AV OEMs, this is an example of how governments may continue to work on ways to help the proliferation of AVs.

1.2.2.2 Changes in the Automated Vehicle Landscape

The AV landscape continues to progress and change, with new technologies, manufacturers, partnerships, and systems developed at a rapid pace. Since this RUC/AV Demonstration Project was conceptualized, changes in AVs have occurred that have been influenced by the COVID-19 global pandemic, the new Biden administration, OEM strategies, and changes in investments, to name a few.

[7] Harris, Nick. 2021. "Light is the key to long-range, fully autonomous EVs." Accessed November 18, 2021, https://techcrunch.com/2021/05/24/light-is-the-key-to-long-range-fully-autonomous-evs/.

[8] U.S. Department of Transportation, Federal Highway Administration. 2012. *Manual on Uniform Traffic Control Devices*. Accessed November 18, 2021, https://mutcd.fhwa.dot.gov/.

SAE INTERNATIONAL

SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged - even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged - even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehcile under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency brake • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

For a more complete description, please download a free copy of SAE J3016: https://www.sae.org/standards/content/J3016_201806/

Figure 8: SAE Levels of Automation (www.sae.org)

Relating to the RUC/AV Demonstration Project, the RUC West program should consider the following changes, or trends, in the AV landscape:

- **Location on the Gartner Hype Cycle –** Gartner has developed a well-referenced curve that addresses a commonly understood trajectory of new innovations and technologies. This curve tracks how, over a course of time, the expectations of these innovations change. AV expectations will continue to adjust to a "plateau of productivity," meaning the systems that make up an AV will continue to be refined to meet real-world needs rather than loftier or unnecessary requirements. Figure 9 shows the Gartner Hype Cycle and describes the different regions of the curve, which compare expectations over time.
- **Changes in government oversight –** In January 2021, the U.S. DOT published its third update to their *Automated Vehicles Comprehensive Plan*.[9] Of note was a change to how the government would be engaged in AV policy. It indicated that there would be increased direction and clarity on regulations for AVs, which is a complete shift for the U.S. DOT to enable a hands-on approach from just six months earlier. This approach will help bring consistency in operations and policy between jurisdictions, to allow seamless operation.

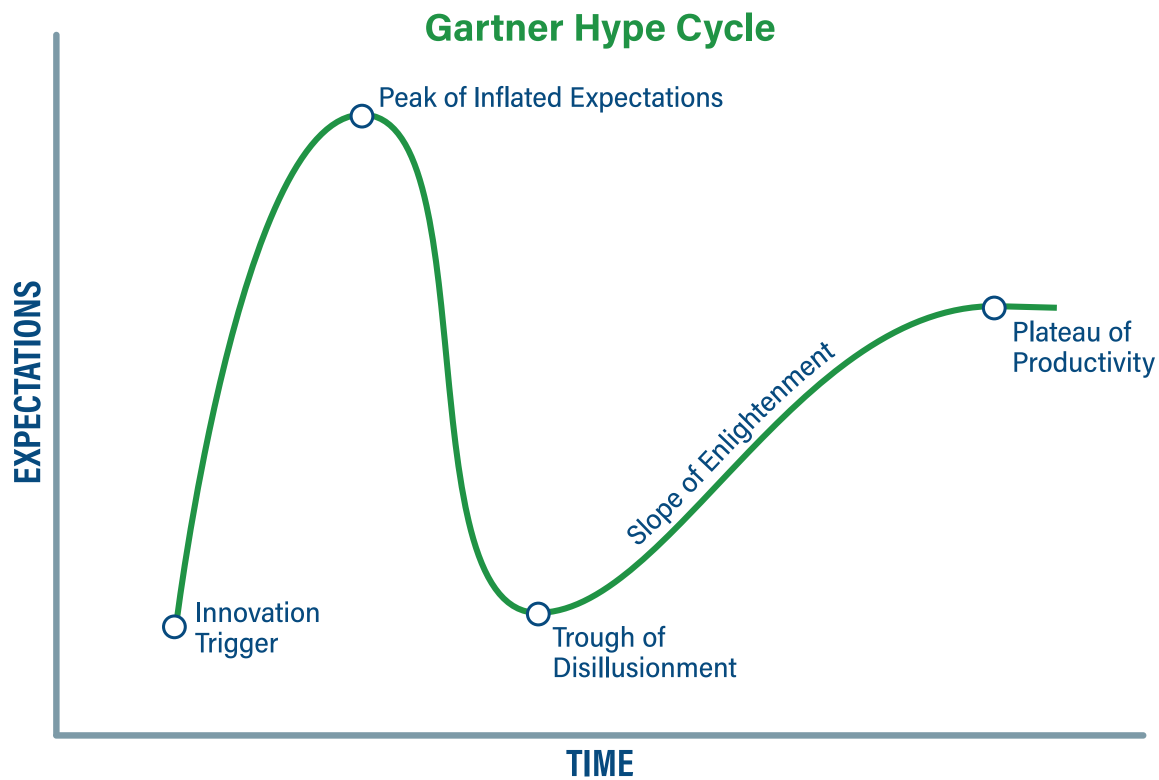


Figure 9: Gartner Hype Cycle & Regions Along Curve

[9] U.S. Department of Transportation. 2021. *Automated Vehicles Comprehensive Plan*. Accessed November 18, 2021, https://www.transportation.gov/av/avcp.

- **Systems standardization –** As more in-vehicles systems are developed, there will be an increased need for standards to be established for systems to work together efficiently to support RUC and other mobility policies seamlessly. Vendors with proprietary implementations usually do not abandon their approach until a viable standard is available to replace it. Generally prominent players will participate in the standards process to influence the way their proprietary implementation gets incorporated into the standard to minimize the impacts of the transition to their systems. Therefore, standards should be developed to allow for improved interfaces between vehicle components designed to be utilized in multiple OEMs. SAE will have a significant role in developing these standards, like J3217, "Profiles for V2X-Based Fee Collection," which is currently a work-in-progress.
- **Connectivity –** Regardless of the systems that are developed and integrated into AVs, data used for RUC will mostly depend on vehicle connectivity. Nearly all vehicles today come off the production line with cellular communications capabilities, usually through telematics or navigation systems. This connectivity alone will allow future vehicles to communicate the data needed for RUC to enable appropriate account management of miles traveled and location data.
- **AV uptake and ownership –** An AV is less likely to be a light-duty vehicle for personal ownership than it will be a fleet vehicle for delivery or shipping, at least until 2030.[10] Investment in AVs for personal use will be too costly for most, but investment in AV fleets and even OEM ownership/leasing will more likely prevail.

1.2.2.3 Exploring the Next Level of Feasibility

It is likely that AVs will be deployed on more than a trial basis before RUC programs evolve into a nationally interoperable system. This study presents an opportunity to investigate whether it might be appropriate to place AVs on a RUC at the state level and eventually in an interoperable regional RUC system.

With Oregon and now Utah each demonstrating the technical and operational feasibility of collecting RUC as an actual (live) tax mechanism, the next level of feasibility with CAVs is ripe for exploration. In a future, when a significant portion of vehicles on the roadway are fully electric, connected, and automated, the following questions arise:

?

- How could RUC be designed to collect taxable mileage data from these emerging technology vehicles most efficiently and effectively?
- Will AVs have built-in telematics capabilities that would enable them to contribute for their use of the roadway fairly and efficiently?
- Is there an alternative RUC process that can leverage advanced AV technology and capabilities to allow states to reduce cost of RUC collection?
- Can AVs act as a trusted source of data and, if so, what type of data must be collected by AVs (and/or their network operators) for the purposes of reporting RUC?
- Which standards should be set up, and how will governments or their trusted private industry partners receive, process, and protect this data?
- What will be the impact on businesses that operate AVs?

These were some of the questions researched and tested in this project sponsored by RUC West and others within the RUC community, and they will be addressed in the following sections of this report.

[10] Travel Forecasting Resource. "Autonomous vehicles: CAV Penetration Rates." Accessed November 18, 2021, https://tfresource.org/topics/Autonomous_vehicles_CAV_Penetration_Rates.html.

2.1 Goals & Objectives

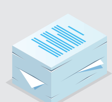
With the understanding that the challenge of implementing RUC for AVs goes beyond data collection, the RUC/AV Demonstration Project includes the goals and objectives summarized in Table 1.

2.1.1 Proof of Concept

The primary goal of the project was to demonstrate technical feasibility of charging RUC to AVs through an automated and direct data exchange. The Collective Impact Team addressed this goal by optimizing the existing RUC platform provided by Azuga to operate with Udelv Level 4 vehicles. The purpose of testing technical feasibility was to show that an automated RUC mechanism could be applied to AVs and to determine if any changes or improvements would be needed to charge RUC to AVs from the RUC system that is in place today.

Udelv committed to participate in the project as an AV vendor by enrolling its Level 4 AVs in the pilot and exchanging data between its AV platform and the project's RUC platform provided by Azuga. Udelv provided four of its second-generation vehicles operating in Texas. These vehicles transmitted driving data during five months to the RUC platform through data exchange interfaces specifically developed for the pilot.

Table 1: RUC West RUC/AV Demonstration Project Goals & Objectives

GOAL	OBJECTIVES
 **Conduct a Proof of Concept.** Demonstrate collection of necessary data for accurate, secure RUC processing for at least one Level 3 or higher AV.	■ Collect necessary data monthly from AVs (Level 3+). ■ Validate and process data on RUC system. ■ Report pilot data to state administrations. ■ Deliver technological and administrative recommendations.
 **Evaluate Impact on Stakeholders.** Determine how a diverse set of AV businesses can be ready to accept and support RUC with minimal impact to their businesses.	■ Understand acceptance factors. ■ Understand impact on AV business models. ■ Deliver solution and user experience design recommendations for AV businesses and states administrations.
 **Advance RUC Policy.** Inform a policy analysis that addresses pertinent issues, potential problems, and opportunities.	■ Collect information from stakeholders to inform policy analysis. ■ Deliver policy recommendations based on possible AV usage scenarios.

In addition to providing technical data, Udelv played a crucial part in pilot evaluation by providing feedback during the participant research phase. Udelv's leadership team, technical team, and operations team were consulted at the beginning and end of the pilot on various aspects, including their overall pilot experience and potential impacts on their business operations.

2.1.2 Stakeholder Impact Evaluation

The stakeholder impact evaluation constituted one of the key pillars of the project approach. The initial phases of the RUC/AV Demonstration Project included industry outreach and stakeholder engagement activities to collect feedback from a variety of AV stakeholders. These stakeholders were from distinct industry segments, including automotive and heavy vehicle manufacturers, delivery service providers, AV technology suppliers, and digital innovation partners.

These committed AV stakeholders participated in workshops and interviews and were consulted through the design phase of the project. All AV stakeholders had the opportunity to provide a wide range of input. The Collective Impact Team specifically sought their input on their business models, as well as regulatory and operational constraints. Their input informed the pilot system design that was implemented with Udelv and a series of forward-looking scenarios (Northstar concepts) that could result from a combined functional RUC/AV implementation.

Besides committed AV stakeholders, the Collective Impact Team continued engaging with fleet operators and AV players across the industry to put into perspective Udelv's pilot participant experience and to better understand the ecosystem in which AVs operate. Thus, the team consulted with fleet management service providers, heavy and light vehicle fleet operators, and additional AV businesses.

2.1.3 Advance Road Usage Charge Policy

While this project was intended to demonstrate the feasibility of RUC for AVs, there was an opportunity to explore more RUC/AV-related issues within the project's group of AV stakeholders. Thus, the team added a complementary goal to investigate the impact of using AVs on a range of issues that are being researched more broadly in the context of RUC today. These issues included the following:

- Open standards
- Privacy and data security
- Convenience/usability
- Reduction of data collection costs
- Related AV policies
- User acceptance

2.2 Project Organization

To meet project goals and objectives, the Collective Impact Team organized the project in three main phases (Figure 10), each designed to produce the following distinct outcomes:

- **Discovery phase –** Industry outreach, preliminary research, and concept generation activities. The goal of the discovery phase was to generate a RUC/AV pilot concept led by Udelv, the AV vendor, to demonstrate technical feasibility and generate forward-looking (Northstar) concepts that would inform longer-term mobility policy goals relating to AVs.
- **Design and development phase –** Solution design, development, and testing activities. The goal of this phase was to convert the RUC/AV pilot concept into a pilot system that could be tested with an existing RUC platform (provided by Azuga) using Udelv's data reporting capabilities.
- **Pilot operations phase –** Pilot operations and data reporting, culminating in a participant research activity with Udelv and additional fleet operators to enhance the AV fleet perspective. The primary goal of the pilot operations phase was to demonstrate that data could be reliably collected from Level 4 AVs and applied to RUC. A secondary goal was to capture feedback on usability and convenience of the RUC/AV pilot solution for AV fleets.

These three phases are further detailed in the following subsections.

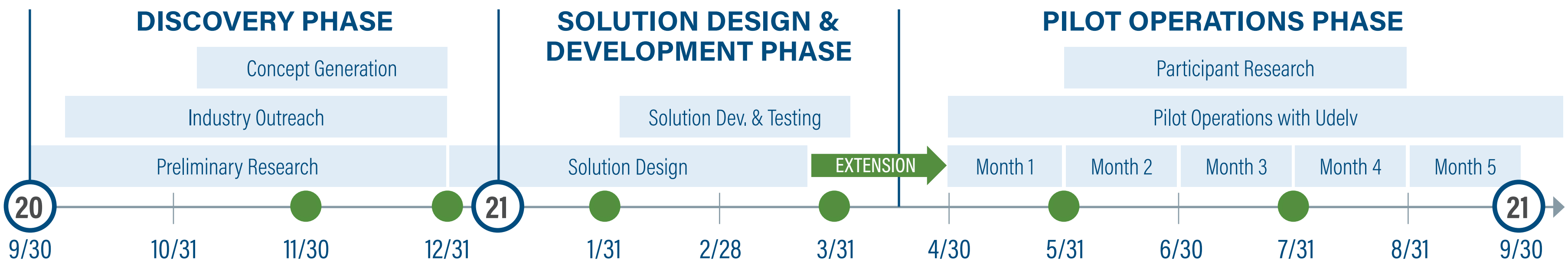
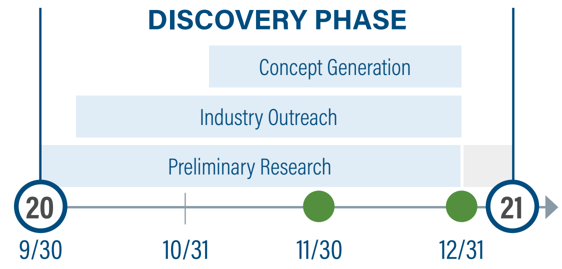


Figure 10: Project Phases

2.2.1 Discovery Phase

The first three months of the RUC/AV Demonstration Project were dedicated to the discovery phase, which included industry outreach to engage with AV stakeholders and preliminary research to understand AV capabilities. The discovery phase culminated into a series of concept generation and co-creation activities involving AV stakeholders and subject matter experts (Figure 11).



The goal of these activities was to foster an environment that allowed for diverse feedback to gain a common understanding of RUC requirements and AV business models, technologies, and data structures to develop a vendor-agnostic RUC-for-AV concept. During concept generation workshops, the team collected information on AV stakeholders' business models and regulatory and operational constraints, and sought to gain a deeper understanding of their capabilities to support RUC.

2.2.1.1 Co-Creation Activities

The team created the highest-level description of a RUC process that did not include any preconceived notion of how AV businesses or OEMs should implement RUC. The intent of this blue-sky approach was to elicit unconstrained feedback from a wide variety of experts and AV stakeholders to open up the possibility of eventually departing from the traditional RUC processes implemented thus far for conventional vehicles.[11]

This approach allowed the Collective Impact Team to:

- Identify opportunity areas to design a forward-looking RUC/AV process that would leverage AV capabilities to the extent possible to address typical RUC issues such as privacy protection and reduction of the cost of collection.
- Mitigate the risk of designing a system ill-fitted to AV businesses' needs. The goal was to inform a flexible, future-proof, user-friendly solution that could eventually be tested in a pilot setting.

CONCEPT GENERATION WORKSHOP	AV STAKEHOLDER INTERVIEWS	SYNTHESIS & IDEATION
AV stakeholder participated in an online workshop focused on gathering feedback on a sample RUC system/process in order to identify gaps in perception, pain points, needs, and opportunity areas for the AV fleet context.	Leading up to and after the workshop, interviews with workshop participants to gain deeper understanding of perspective and to help validate some of the initial post-workshop opportunities and ideas.	Project partners collaborated to identify key themes and opportunities in the resulting content from the workshop and interviews. Concepts were generated and documented.

Figure 11: Key Engagement Activities

[11] Stakeholders included AV fleet operators, AV manufacturers, CAM software developers, and CAV and mobility experts.

2.2.1.2 Opportunity Areas

During co-creation activities, AV stakeholders identified several opportunity areas that should inform the design of an optimal RUC solution for AV fleets. The three most prominent opportunity areas are summarized as follows:

Maintain Convenience

Current fuel taxes are collected at the point of sale, making the payment process passive and nearly invisible. In contrast, the typical RUC journey includes several steps requiring active participation. AV stakeholders who participated in the concept generation workshop were hesitant about engaging with a new process, preferring instead that the RUC be as effortless as the fuel tax.

Exploit AV Capabilities

During the workshop, AV stakeholders felt they could easily help calculate RUC. AVs already collect location and distance data; in most cases, everything needed for RUC can be calculated on the vehicle. AV stakeholders expressed interest in participating more in the RUC process, not just serving as a data source.

Protect Data Privacy

Workshop participants were concerned about companies mining and monetizing AV fleet owners' data. AV operators are measured on the number of automated miles they have driven; making this information public through RUC could impact their reputation and reveal important information to their competition on the maturity of their technology and business operations. Any solution should seek to protect users from risks to their commercial confidentiality.

Forward-Looking Road Usage Charge/ Automated Vehicle Process Flow

Using the three opportunity areas as a guideline and eliciting further AV stakeholder input, the team designed an alternative RUC process flow. This new process envisioned how OEMs could play a more important role in supporting RUC functions by leveraging their connectivity infrastructure and inbuilt data processing capabilities by making AVs a trusted source of RUC data. This alternative, forward-looking RUC process is named the OEMPlus RUC Process Flow.

In the traditional or standard RUC process flow currently implemented for light vehicles in the OReGO and Utah DOT RUC program, commercial account managers (CAMs) receive granular trip data from light vehicles that are either equipped with plug-in devices or have enabled telematics systems. The CAM collects granular trip data sent by the vehicle, maps it to pricing zones, and then processes it into a RUC (and collects the revenue).

The OEMPlus RUC Process Flow (OEMPlus concept) is built on the idea that CAVs already have the technology on board to identify and report their location, and they can recognize when they have entered a certain geographic area. Therefore, instead of sending granular trip data to CAMs several times per day, OEMs could collect data that are matched against geographic references, such as load boundaries for pricing zones as geofences on AVs, which would allow the vehicle systems to count the number of miles driven within each pricing zone. The result would be that the vehicle would store the pre-processed and aggregated mileage data (mileage per zone, per day, or per month) on the vehicle and communicate these aggregated data to the CAM on a less-frequent basis. This architecture would present the following benefits for AV fleets:

- Smaller amounts of data would need to be transmitted from the vehicle less frequently than in the traditional RUC process, reducing communications costs.

- No post processing would be required by the CAM to determine RUC zones for pricing (this could potentially have cost reduction benefits).
- All the AV fleet vehicles' detailed trip activity remains private.

The process flow in Figure 12 shows how OEM participation in RUC calculation (data collection, processing, and mapping to charging areas) could increase convenience and privacy protection for AV fleets operators through two scenarios: owner-centric and wholesale. Both scenarios are based on AVs having the capabilities to function as a trusted source of RUC data.

- In the owner-centric scenario, OEMs would enable AV capabilities such that AVs become a trusted data source for RUC. AVs would calculate mileage per pricing zone (and could identify distance on public roads separate from distance on private land) directly and send aggregated data to CAMs periodically, protecting the privacy of the owners' operations.

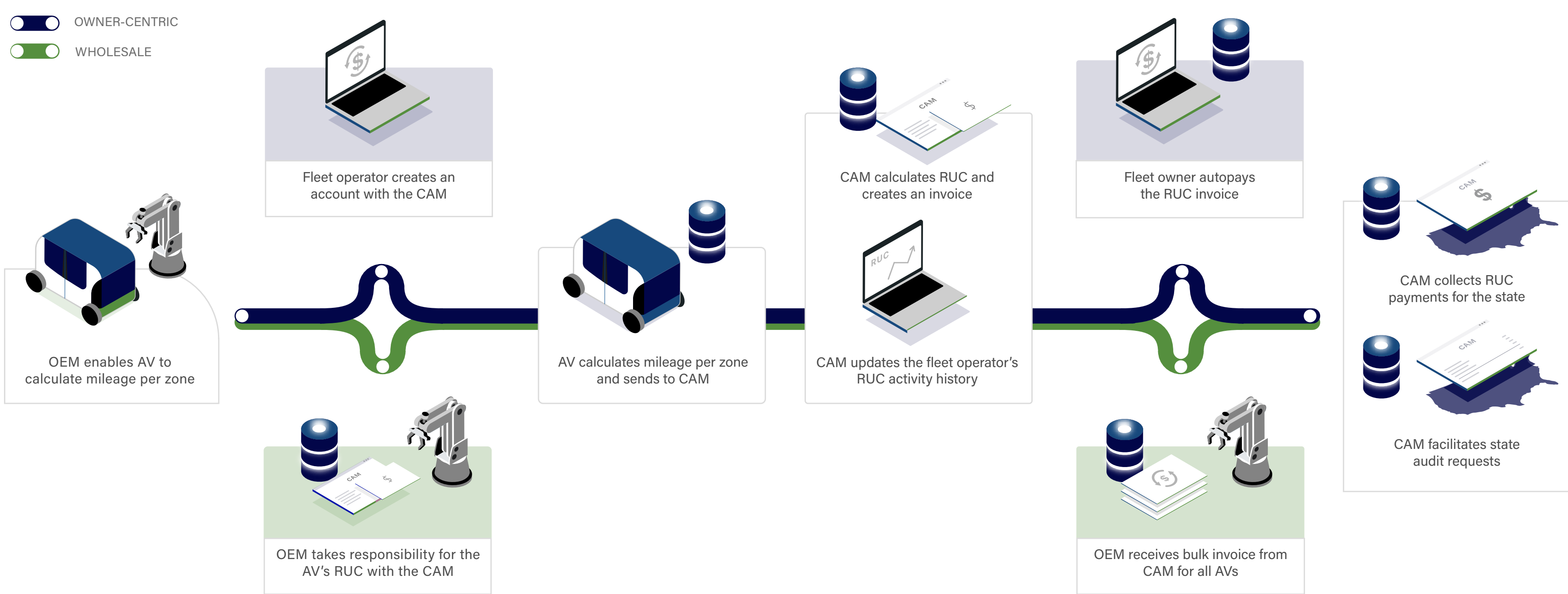


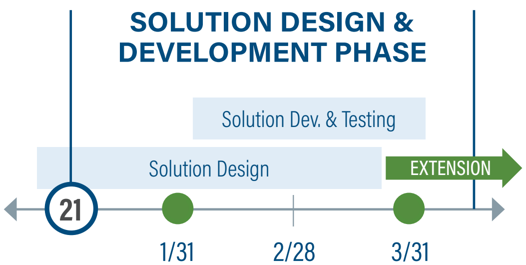
Figure 12: Process Flow Showing OEM Participation

[12] This architecture is similar to the thick client concept used in telematics onboard units (OBUs) in Europe in the 2000s in which the OBU has an application-processing capacity and processes everything onboard. The OBU has a MapInfo mapping interface (MMI) that contains maps and builds toll/tax transactions on its own. The main issue is that maps need to be updated for roads to be identified as public roads so that off-road distance could be excluded. Since AVs have advanced mapping capabilities and would need up-to-date maps, this concept would be more feasible for AVs. https://www.intelligenttransport.com/transport-articles/1886/introduction-of-gnss-technology/

- The wholesale scenario goes one step further. In this scenario, OEMs would assume responsibility of collecting RUC fees from AVs and remitting the fees to the CAM, acting as a fleet operator with thousands of cars. The OEM would maintain the direct relationship with AV fleet operators and interface with the CAM on behalf of all its AVs. This presents the benefit of eliminating administrative touchpoints for AV fleet operators.

Northstar Concepts

The Collective Impact Team built on the OEMPlus RUC Process Flow and generated a collection of independent, forward-looking concepts called Northstar concepts. These concepts highlight opportunities to leverage AV technology to maximize convenience for fleets while providing benefits to society. These concepts are under section 5.1 – Northstar Concepts.

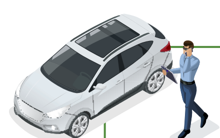


2.2.2 Pilot Solution Design, Development, and Testing Phase

In the solution design, development, and testing phase, the Collective Impact Team took the concepts generated during the discovery phase and created a pilot system to demonstrate the feasibility of implementing those concepts in a real-world application. While the discovery phase produced a complete OEMPlus RUC Process Flow concept, it was important to scale down that concept into one that would be feasible and implementable in a limited scale pilot. This scaled version of the OEMPlus concept is referred to as the minimum viable product (MVP) pilot concept and is further detailed in the following section.

2.2.2.1 Minimum Viable Product Pilot Concept

The pilot concept was based on an MVP approach. This essentially meant trimming down the OEMPlus RUC Process Flow designed in the discovery phase to a pilot version that was feasible to implement in the time and budget available. The MVP would focus on the most important functions the pilot had to demonstrate—automated data exchange between a RUC platform and AV platform operating vehicles with Level 4 autonomy.



Besides the feasibility of the data exchange, the MVP pilot concept was meant to validate the most important aspects of the RUC-for-AV concept:

1. Test convenience of the RUC/AV solution for an AV fleet operator.
2. Leverage AV technology to reduce cost of RUC data processing.
3. Protect privacy (or more specifically commercial confidentiality) of fleet operators.

Figure 13 illustrates elements of the OEMPlus RUC Process Flow that were included in the pilot concept and elements that were eliminated to produce the MVP pilot concept.

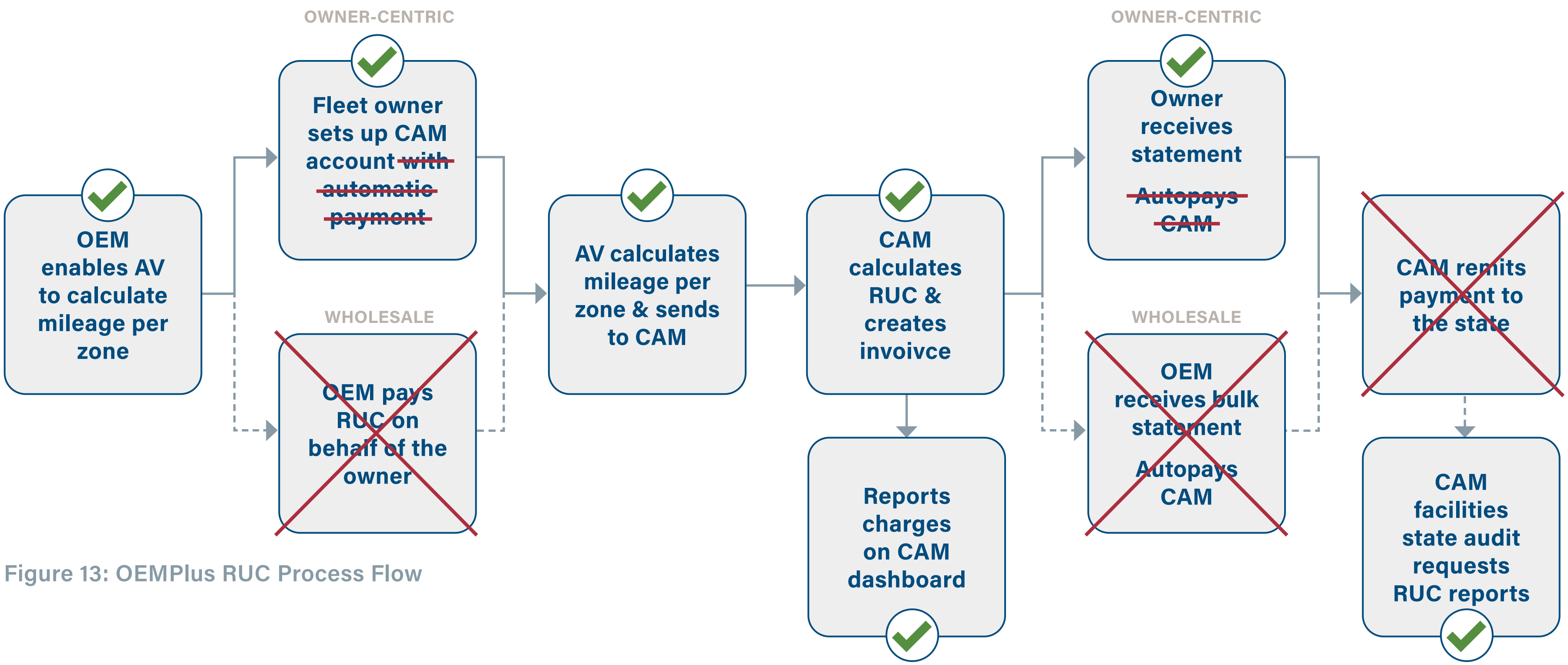


Figure 13: OEMPlus RUC Process Flow

The resulting MVP pilot concept included the following pilot usage scenarios to provide Udelv (as an AV fleet owner) an end-to-end RUC experience with a certified CAM, Azuga:

1. Fleet owner account set-up with CAM
2. Registration of fleet owner's AVs with CAM
3. Vehicle data reporting to fleet owner platform through three possible data reporting scenarios: standard RUC data exchange with location, OEMPlus RUC Process Flow aggregated data exchange, and monthly odometer data exchange
4. Fleet owner platform reporting data to CAM platform
5. CAM RUC computation and invoice generation and distribution
6. AV fleet vehicle removal from CAM platform
7. AV vendor unenrollment from CAM platform

While the standard data exchange model (API 1) would allow the Collective Impact Team to validate the feasibility of the data exchange to meet the primary project goal, the goal of the OEMPlus data exchange model was to test capabilities of Udelv's AV fleet platform to do more RUC data processing and act as a trusted source of data.

The additional odometer-only reporting model provided a simplified reporting option to Udelv that would protect privacy for their operations as an AV fleet operator. This option was added to give Udelv the opportunity to compare RUC reporting options across a variety of mileage reporting methods and assess their relevance and convenience for their business.

The MVP included the following three data reporting scenarios:

1. **Standard or traditional data reporting model (Application Programming Interface [API 1]) –** AVs send granular trip and location data to the CAM platform.
2. **OEMPlus data reporting model (API 2) –** AV platform collects data from AVs, maps trip data to pricing zones, and sends pre-aggregated data per AV to the CAM platform monthly.
3. **Odometer-only reporting mode (API 3) –** AV platform would only send odometer (distance) data per vehicle monthly.

2.2.2.2 Coordinating System Design, Development, and Testing

Traditionally, the solutions design for a project includes the development of documents that are part of the systems engineering process, including the concept of operations (ConOps), the system requirements specifications (SRS), and the interface control document (ICD). Then the system development and testing take place to implement the system defined by those documents.

The team documented the MVP pilot system according to the systems engineering process but adopted a flexible design, development, and testing approach to meet the compressed schedule and minimize implementation costs for Udelv in the following manner:

- The team documented a first version of the ConOps that was based on the MVP pilot concept and focused on how the system should be operated. It described the background and environment of the project and primarily focused on the seven usage scenarios from AV vendor enrollment through data reporting to AV vendor unenrollment.
- The team then documented the ICD as it addressed the most important functions that had to be demonstrated—the data exchange scenarios. The ICD defined the data elements included in the interface between the CAM (Azuga) and AV vendor (Udelv) to achieve the data exchange scenarios needed to support the system described in the ConOps. The ICD was implemented as an addendum to the Oregon DOT RUC Program ICD.[13]
- The team implemented a new "bare-bones" SRS for the project based on the solution development that was underway.[14] The SRS included requirements for the technical function of the system (such as distance or location measurement, reporting, and security).

[13] This Addendum identifies which sections of the Oregon DOT RUC ICD are applicable to this pilot, amends Section 2 of the document, and replaces Section 5 Appendix B in its entirety with the APIs that were developed for the pilot.

[14] The SRS was originally intended to be implemented as an addendum to the Oregon DOT RUC SRS. However, because of the extremely limited scale of this pilot, so much of the Oregon DOT RUC SRS would be non-applicable that it was advisable to implement a simplified SRS.

- Azuga started the solution development while the ConOps was still under development. The final ConOps was refined based on decisions that were made during solution development to adjust the concept for Udelv's system architecture.
- The MVP pilot design documents were pared down to the essential elements for Udelv to minimize time to process design documents and make design choices. MVP design documents introduced the overarching MVP pilot concept and focused on the three data exchange scenarios proposed: API 1 (standard data exchange), API2 (OEMPlus data exchange), and API 3 (odometer-only data exchange).

2.2.2.3 Pilot Solution Development with Udelv

In the solutions development phase, the team applied the design documents (ConOps, SRS, ICD) to develop a functioning system. The team primarily coordinated with Azuga and Udelv for development. Udelv helped the team understand their capabilities and ultimately adjusted the concept further based on the design of Udelv's technical platform.

Aligning Pilot Solution to Udelv's System Architecture

Considering that Udelv is a live fleet operator with competing business priorities in addition to being a pilot research partner, there were some key considerations that drove the approach to solution development:

1. The solution had to minimize the cost for Udelv to implement and operate it.
2. The solution had to protect Udelv's privacy as an AV fleet operator.

Based on the discovery phase recommendation for the three pilot APIs, Azuga prepared the interface design, which included the following:

- **API 1 (standard RUC):** Granular data API with GPS points
- **API 2 (OEMPlus RUC):** Pre-processed Udelv data API (with predefined zones)
- **API 3 (simplified RUC):** Odometer-only API

Aguza presented the three API designs to Udelv to assess which ones the team could implement within the compressed time frame. The original design of all three APIs included fields for odometer readings. Since the odometer reading was one data field that could not be accessed from Udelv's current systems without a considerable development effort, the solution design team decided to simplify API 1 and API 2 interface designs further to remove odometer readings from the interface. The team also removed API 3 from the pilot concept, because the priority was to focus on the proof of concept with API 1 and the extent to which API 2 could test the OEMPlus concept.

Udelv provided data via API 1 and API 2 from delivery vehicles operating on three delivery routes in Texas. The APIs were designed to align with Udelv's system architecture and to minimize development efforts for Udelv.

Development of API 1

For API 1, Udelv used the GPS data that the AVs already reported to central servers to generate granular API 1 messages. Its system sent GPS data every second along the delivery route (from warehouse to delivery location and back to the warehouse) as a single trip and transmitted that data as an API 1 trip message to the Azuga RUC platform. Udelv developed a cache system to store the GPS points generated every second of each trip. This additional development allowed the team to meet all the requirements to test the granular data exchange with Azuga's platform.

Development of API 2

For API 2, the OEMPlus concept could not be implemented as designed in the limited time frame; Udelv's systems were not designed to store trip data. Thus, monthly data aggregation and automated mapping to charging zones would have implied a nontrivial development effort for Udelv. However, to simulate the way the OEMPlus RUC Process Flow could work, Udelv offered to provide data it was tracking for its operation on its fixed delivery routes in Texas. Udelv planned and kept track of the number of trips made for each fixed delivery route by all vehicles that drive that route. Consequently, Udelv could estimate the mileage driven by each vehicle based on the length of its fixed delivery routes and provide total miles driven for each route at the end of each month through API 2, allowing the team to simulate mileage aggregation per route.[15]

Development of Geofences to Simulate Interstate Travel across Pricing Zones

All RUC miles driven during the pilot were from AVs operated in Texas. Since RUC systems would need to be able to operate in multiple states, or potentially multiple charging zones within a state, the team decided to simulate geographic interoperability.

To simulate interstate travel and application of different pricing zones to mileage data collected across both APIs, the team created geofences based on the three fixed delivery routes. Therefore, both APIs were developed so that any travel the AVs reported within the three geofences would be mapped to the simulated charging zones representing Oregon, Washington, and Utah. Any travel outside these three geofences would be mapped to the Texas charging zone. As shown in Table 2, each pricing zone had a zone number, a RUC rate[16] applied to miles driven, and a gas tax rate applied on estimated fuel consumption to determine fuel tax credits for gasoline-powered vehicles.[17]

Table 2: Chargeable Zones & Rates

RULE ID	UDELV ROUTE #	ZONE	SIMULATED STATE	PER-MILE RATE (Cents per Mile)	GAS TAX CREDIT (Cents per Gallon)
41	10-31	1	Oregon	1.8	0.36
53	99-12-36	2	Washington	2.4	0.494
49	17-28	3	Utah	1.5	0.314
48	–	4	Texas	0.0	0.0

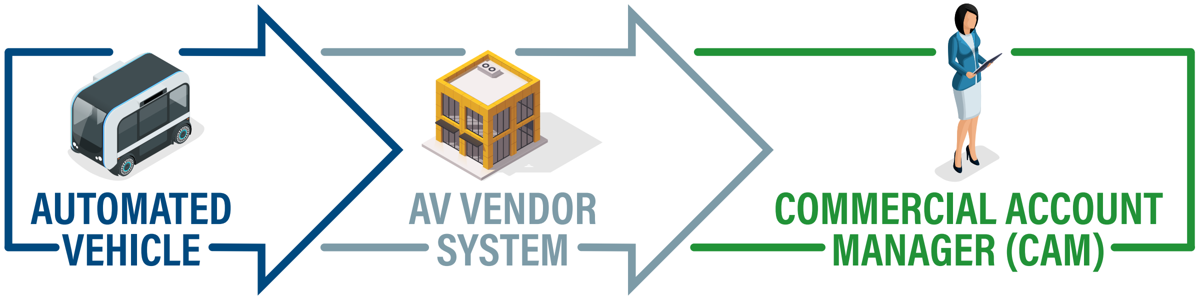
15 This approach would not capture any additional mileage driven by the vehicles outside the delivery routes or any deviations to the usual route during delivery runs.

16 These rates are illustrative and are not recommendations of rates that should be applied to this category of vehicles.

17 Fuel usage data were not easily accessible, so fuel usage fields were removed from the APIs.

Adjustments to the Azuga RUC platform

The system architecture developed followed the pattern of many RUC West programs:



Azuga's original RUC platform had most of the building blocks in place to support the RUC/AV usage scenarios. However, since one of the priorities of the project was to enhance the AV fleet operator experience, Azuga optimized its user interfaces to minimize Udelv's fleet enrollment and development efforts to the extent possible. Azuga conducted the following adjustments:

- Optimized user interfaces to improve fleet enrollment experience. This included changing information presented on the fleet dashboard to include digestible charts, basic metrics on vehicle fleets enrolled, miles reported, and total RUC paid.
- Developed an upload process for fleets to import their vehicle lists efficiently.
- Developed an API reference library to help fleet operators set up their data-exchange integration with minimal effort by signaling data elements needed clearly.
- Developed two APIs refined to align Udelv's system architecture.
- Developed geofences to simulate interoperability.

2.2.2.4 Solution Testing

Once the team agreed on the API 1 and API 2 specifications, Azuga and Udelv coordinated to complete their respective implementations. Integration testing began on April 1, 2021, in the development environment and lasted three weeks. Azuga and the testing team, led by Jacobs, analyzed the test results (i.e., the trip messages) separately.

Test Vehicles

Udelv provided four of its delivery vehicles operating in Texas to the project, which included one AV and three discovery vehicles.[18] The discovery vehicles were being trained to operate at Level 4, so they were mainly operated by a driver. The key difference for the data exchange scenarios was that while data for the AV was automatically collected and transferred continuously from the vehicle telematics to the AV fleet platform, data collection for discovery vehicles had to be triggered manually.[19] For discovery vehicles, the data transfer was a manual process that relied on the driver to activate the transfer of trip data from a GPS-enabled app on a smartphone. This meant that data generated from discovery vehicles were inherently less reliable than the AV data.

The team focused on validating data generated by the AV through API 1, since this was the primary objective of the pilot. However, the team deemed it useful to collect data from the discovery vehicles for both APIs. Since Level 4 AVs were designed to operate in either fully automated mode or manual mode, it would allow the team to see limitations of data exchanges when AVs function in manual mode. Collecting data from discovery vehicles would also allow the team to gauge reliability of the monthly aggregated mileage data–reporting mechanism that was set up for API 2.

Validating Automated Vehicle Level 4 Data

Once Azuga started receiving and processing data from API 1, the testing team calculated the mileage from the API 1 GPS data independently from Azuga. The test team devised a method that involved creating a table of the GPS points received from each trip for API 1 and importing the data into Google Earth, displaying the route of the trip. With the trips plotted out on Google Earth, the team could verify that GPS points were continuous and mapped correctly to the Azuga geofences. This method also allowed Azuga and the test team to identify issues effectively (missing GPS points or GPS points that deviated from fixed routes).

The testing team compared its results with Azuga's test results and documented any discrepancies. Azuga made some adjustments to their calculations after the testing team observed some initial discrepancies. Following the modifications, mileage calculations from both the test team and Azuga tracked each other very closely and allowed the Collective Impact Team to draw the following conclusions:

- **API 1 Testing —** Data generated by the AV over API 1 were accurate and reliable. Initial testing revealed some issues with inconsistent time zones used for different time stamps in the API messages, but after correction of these issues, GPS data were transferred successfully over the API. Given discovery vehicle data were also included and manually triggered, the team confirmed the number of trips with Udelv to ensure that the data received through API 1 were complete.

- **API 2 Testing —** API 2 data were consistent with the number of delivery runs for each route during the test period plus the expected number of delivery runs during the beginning of the month before the start of the test.[20]

Additional Testing with Discovery Vehicles

Discovery vehicles were not designed to provide GPS location data back to the servers; instead, the discovery vehicles relied on the vehicle operators' smartphone app to capture the location data. Operators had to manually start and stop GPS data collection by swiping the app on the phone at the start and end of each trip. All GPS points collected by the app between the start and stop swipes were also

[18] In addition to the AV, Udelv also operates what they call a "discovery vehicle," which is operated by a human driver, not autonomous, and instrumented to collect data for future autonomous operations on the route. Discovery vehicles are also used for deliveries on the same predetermined routes as AVs. All routes are driven multiple times per day, generally with one delivery trip per hour throughout the day.

[19] Once the AV starts operating on the fixed delivery routes, data collection is automatically triggered and GPS points are collected.

[20] The aggregated monthly mileage data received on API 2 covered not only the period of the system acceptance test, but also the period from the start of the month to the start of the formal test.

sent in a single API 1 trip message, so the responsibility was on the operators to start the app when departing the warehouse and stop the app on return to the warehouse.

After testing, the team concluded that the data-reporting mechanism of the discovery vehicle was not fully reliable, because there were no operational constraints that compelled operators to start the trip on the app when the vehicle was leaving the warehouse for a delivery run and/or stop the trip on the app at the warehouse upon return at the end of the run. Because of the high potential for operator error with the use of the app, the number of trips taken each day during the testing was regularly confirmed with Udelv for each route. This indicated that there would be challenges in full-scale implementation if this solution were to be pursued further.

Decision to Transition from Testing to Soft Launch

Integration testing continued for about three weeks until the team was confident that all remaining issues were attributable to the observed operator errors in the use of the app in the discovery vehicles. Because this operator error is outside the control of the consulting team for the pilot, the team decided the pilot could be moved to the production environment to conduct a "soft launch" or formal system acceptance test using a formal test plan prepared for the project. The pilot system passed the system acceptance test, which allowed the team to officially launch pilot operations on May 1, 2021.[21] The System Acceptance Test Tech Memo documents the results of the system acceptance test.

2.2.3 Pilot Operations Phase

2.2.3.1 Collecting and Reporting Pilot Data

The pilot launched on May 1, 2021. Its primary goal was to confirm the feasibility and reliability of data exchange between AVs and the RUC platform through API 1, the standard data exchange. In addition to validating data exchanges through API 1, the pilot team tested API 2, OEMPlus data exchange, to evaluate its plausibility and level of convenience for AV fleets. The pilot team used API 1 data as a baseline to gauge the viability of API 2 data.

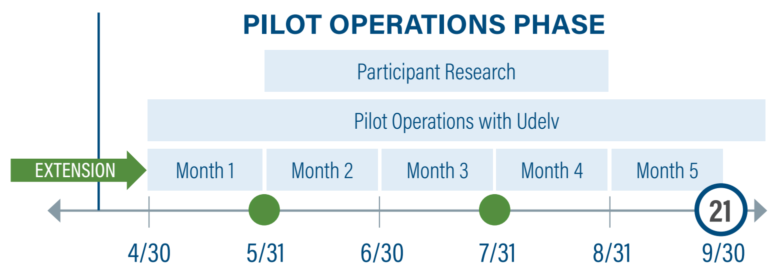


Figure 14 shows data reported across the four simulated pricing zones—Oregon, Texas, Utah, Washington.

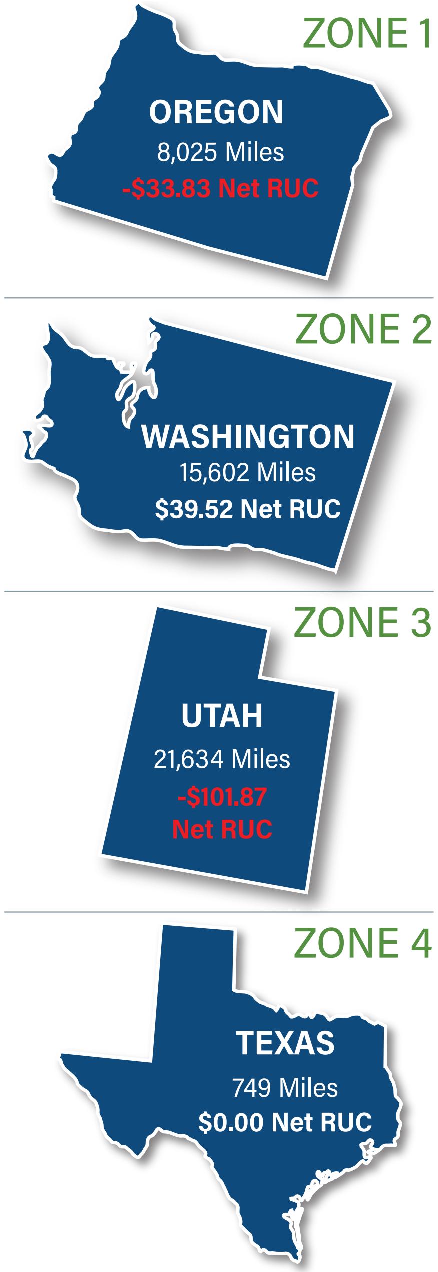


Figure 14: Mileage & Revenue Collected per Zones

[21] The team analyzed all the trip files received on API 1 in Google Maps for the duration of the acceptance test to ensure the AV data generated through API 1 were accurate and reliable, and that any issues were solely caused by manual operator errors on discovery vehicles.

Table 3: Rates Applied per Pricing Zone

SIMULATED STATE (Pricing Zone)	PER-MILE RATE (Cents per Mile)	GAS TAX CREDIT (Cents per Gallon)
Oregon (Zone 1)	1.8	0.36
Washington (Zone 2)	2.4	0.494
Utah (Zone 3)	1.5	0.314
Texas (Zone 4)	0.0	0.0

Table 4: Summary of Mileage & Revenue Data

MONTH	MILES	RUC	FUEL TAX CREDITS	NET REVENUE
May	11,358.6	$206.75	-$230.09	-$23.34
June	11,977.4	$213.27	-$240.57	-$27.30
July	11,419.8	$208.10	-$234.06	-$25.96
August	11,254.6	$213.61	-$233.19	-$19.58
September	9,261.3	$178.42	-$190.76	-$12.34
Cumulative Total	**55,271.7**	**$1,020.15**	**-$1,128.67**	**-$108.52**

Each pricing zone used different per-mile rates, and gas tax credits rates as summarized in Table 3. The per-mile rate used in the table are indicative rates used to illustrate how the RUC/AV pilot system worked. These rates were chosen on the basis of rates currently applied in the Oregon and Utah RUC programs and in the first Washington pilot for light vehicles. These illustrative rates are not policy recommendations.

Table 4 summarizes the monthly data collected through API 1 from May to September 2021. As aforementioned, the rates used are illustrative and are not recommendations on rates that should be applied to this category of vehicles. A RUC (less credit for the estimated gas tax) was computed for mileage driven and recorded during the pilot by Udelv's vehicles. Since Udelv did not collect fuel usage data for its internal combustion engine (ICE) vehicles, the fuel consumption was computed based on the Environmental Protection Agency estimates for the vehicles.

2.2.3.2 Comparison of API 1 and API 2

Figure 15 provides a comparison of miles for API 1 and API 2 and illustrates the difference between the data exchange scenarios as recorded during the pilot.

On average, the difference was approximately 6 percent (%) (with API 2 mileage higher than API 1), mainly attributed to operator error on the smartphone application.

During the acceptance test, the estimated average unreported miles was 5.2%, reportedly attributable to the inconsistency in starting and stopping the app at the start and end of the delivery trips. It is likely that some portion of the difference between the API 1 mileage and the API 2 mileage is the result of portions of the API 1 trips that were not captured as a result of these types of operator errors observed during testing.

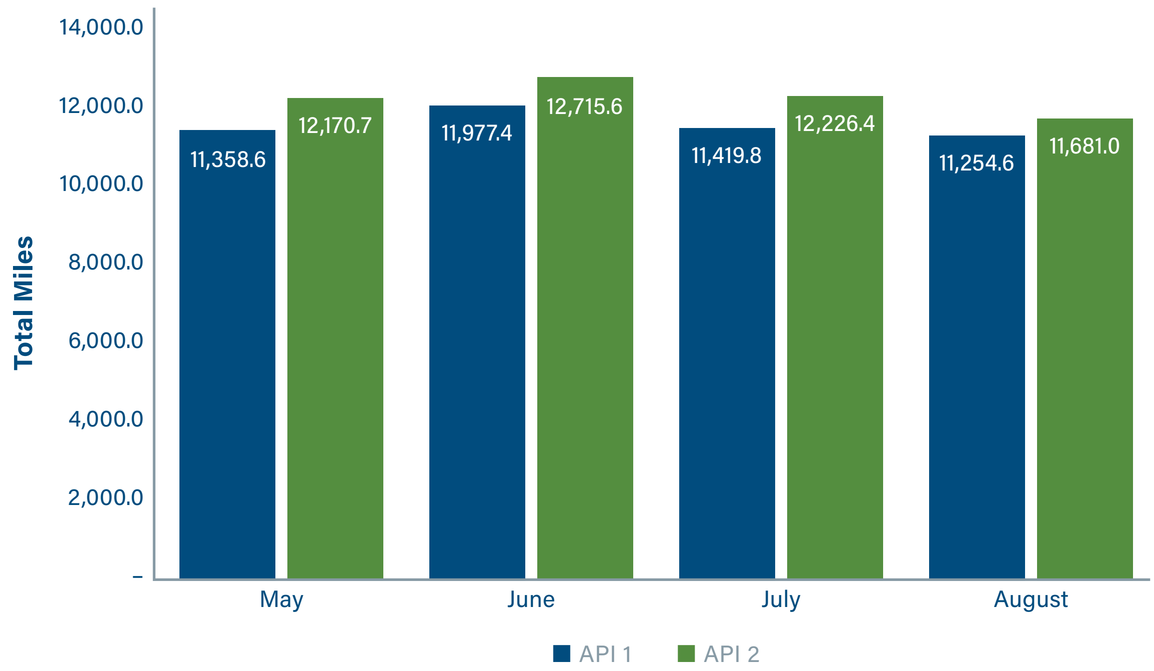


Figure 15: Comparison Between API 1 & API 2

Pilot operations allowed the Collective Impact Team to draw the following conclusions:

Data exchange through the standard data exchange scenario (API 1) is reliable. Data collected through API 1 from the AV Level 4 platform were accurate and complete, and could be successfully mapped through geofences that simulated different pricing zones. These data could be used to reliably calculate RUC charges per pricing zone and produce monthly RUC invoices.

Data exchange through the OEMPlus exchange scenario (API 2) closely aligned with data obtained from API 1, but its integrity (accuracy, continuity, and completeness) could not be guaranteed, because there were no data reporting standards, and operational exceptions could not be captured automatically. Therefore, the data transfer through API 2 did not confirm the ability of an independent AV fleet operator platform to act as a trusted source and aggregate data for RUC purposes. In the absence of a trusted mechanism to aggregate RUC data on the vehicle, AV businesses would need to report data through a certified third party—in other words, a CAM.

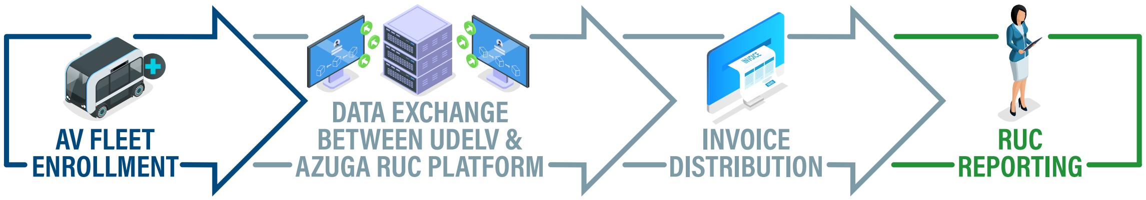
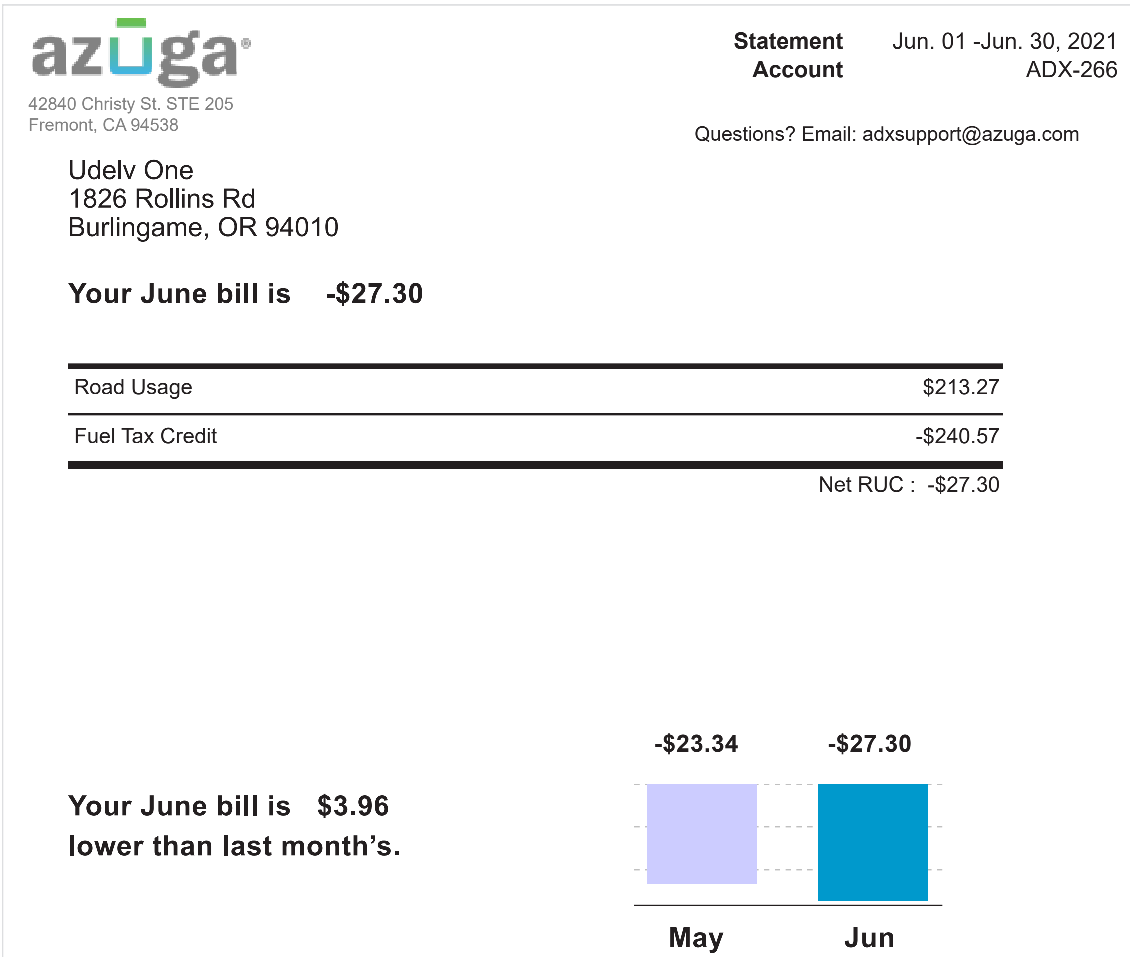


Figure 16: Automated Vehicle Enrollment & Reporting Process


azuga

42840 Christy St. STE 205
Fremont, CA 94538

Statement Jun. 01 -Jun. 30, 2021
Account ADX-266

Questions? Email: adxsupport@azuga.com

Udelv One
1826 Rollins Rd
Burlingame, OR 94010

Your June bill is -$27.30

Road Usage	$213.27
Fuel Tax Credit	-$240.57
	Net RUC : -$27.30

Your June bill is $3.96 lower than last month's.

Figure 17: Monthly Statements Distributed to Udelv

2.2.3.3 Front-End Experience

After both data exchanges were automated, the intent was to expose Udelv to the front-end experience. Even though Udelv had to provide data through two data exchange scenarios, it was important to provide a single front-end experience that was as lean and hassle-free as possible. This would set the stage for improvements through participant experience interviews.

On the front end, Udelv created a single account and provided Azuga with the vehicle identification numbers (VINs) for the vehicles enrolled in the pilot. Azuga then uploaded VINs into their system.

Azuga then distributed monthly statements to Udelv (Figure 17), which included the RUC and mileage recorded by the simulated states for both APIs.

Udelv was not involved in RUC reporting to RUC West. The project team summarized the raw data Azuga provided for both APIs in monthly reports that were shared with RUC West. These reports documented the accuracy of API 1 and compared API 1 and API 2 data. They were marked as confidential, because they shared detailed delivery route data from Udelv's fleet vehicles from its live operations.

While the goal of the pilot was to test and validate methods for data sharing between AV telemetry and RUC systems, the team also explored participant research activities to examine opportunity areas and constraints under which live AV fleets operate.

The pilot was not staged for a service-design study, so the Collective Impact Team assessed the piloted system from the standpoint of a user—in this case, Udelv—as the AV fleet owner. This meant surfacing potential user pain points, understanding and prioritizing user needs, and identifying ways to incorporate those needs into an improved service design.

To contextualize pilot observations and discovery phase learnings, the team interviewed experts from across the field, including fleet operators, fleet management solution providers, and other OEMs outside of the project. This additional research allowed the team to better understand the acceptance factors of RUC as an infrastructure funding source among AV stakeholders to inform policy, technology, and administrative recommendations from the perspectives of both the AV businesses and the state administrations.

Combined findings from participant research activities and pilot operations findings are grouped in the following four sections:

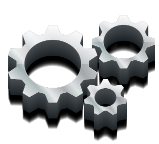
Open Standards

Convenience/Usability

Cost of Collection

User Acceptance

3.1 Open Standards



Development and use of open standards are the fundamental objectives of RUC West. Using published standards open to all vendors ensures that the market for RUC collection vendors is open and allows new entrants at suitable times so no vendor has a de-facto monopoly. The introduction of AV may expand the scope of existing RUC standards or create the need for new standards.

3.1.1 Data Exchange Through Built-In Telematics

Pilot Findings

- Charging RUC to AVs based on data reported through APIs is feasible, as demonstrated in the pilot with the API 1. However, all businesses operating AVs currently may not have easy access to the needed data (e.g., vehicle odometer or optionally fuel consumption data) because their platforms have not been designed to report RUC data optimally. Udelv stated that while odometer readings were captured in their system, they were not easily accessible, so it could not provide this data without investing some development effort.
- Fleet businesses (and AV businesses in particular) design their systems in priority to meet their specific automation and operational needs. Furthermore, no RUC reporting standards have been defined for automated data exchanges. Thus, heterogeneous AV platforms exist, which may mean capabilities with respect to RUC reporting would vary widely.

Recommendations

- Work with standards bodies to create explicit RUC data standards to include what data are needed, to what minimum specifications, and how frequently it needs to be reported. The following standards may be of interest:
  - SAE J3217 as a protocol to use for RUC data collection[22]
  - SAE J2945/C for probe data collection, including traffic management data, road weather data, road maintenance information, etc.
  - ISO 21177 for securing the link between the vehicle and the CAM or data repository[23]
  - FIPS 140-3 for security and encryption standards to ensure integrity and continuity of vehicular data[24]
- Engage with OEMs and fleet management services as much as practicable to ensure these standards emerge and can be made accessible to fleet operators without requiring additional investments.

[22] SAE J3217 is in development and will support RUC. J3217 will be published in calendar year (CY) 2021, and it includes mileage-based "tolling" as well as more traditional architectures for tolling.

[23] It uses IEEE 1609.2 certificates with traditional transport layer security, which is a common method for securing internet connections. IEEE 1609.2 certificates may be useful because the certificate authority responsible for distributing them is focused on transportation applications.

[24] National Institute of Standards and Technology. 2019. "Security Requirements for Cryptographic Modules." Federal Information Processing Standards Publication 140-3. https://csrc.nist.gov/publications/detail/fips/140/3/final

3.1.2 Self-Aggregation Standards

Self-aggregation of mileage and location data (according to the OEMPlus concept) is a desirable feature for states, providing more choice to vendors and exploring potential to reduce costs by leveraging advanced AV technology. However, AV vendors who provide aggregated data will need to be certified as a trusted source. While some AV vendors might want to aggregate the location data themselves to protect sensitive operational data, they might not have the capabilities to aggregate data reliably to meet RUC reporting needs.

Pilot Findings

- During the discovery and design phases, AV stakeholders expressed interest in self-aggregation of trip data to protect commercially sensitive information.
- Udelv provided self-aggregating distance-traveled values, but Udelv's computation for API 2 reported expected miles driven on pre-determined routes rather than actual miles recorded. This would suggest that self-aggregating data are not as simple for AV fleet operators as initially imagined.

Recommendations

- Require data aggregation enabled by vehicle fleets (OEMPlus concept). For example, 99% of miles driven using a global navigation satellite system (GNSS) signal should be assigned to states in which the miles were driven, and there should be specific rules about how to assign miles driven with no or a weak GNSS signal. These requirements should include auditability requirements; at a minimum, it should include maintenance of raw and processed data for a certain amount of time so that end-user fleet data can be used in an audit.
- Work directly with OEMs and AV providers to design the OEMPlus concept, because it may be easiest from the perspective of RUC policymakers.[25] OEMs and AV providers may be able to provide software that is present in every vehicle, or at least available on their servers for every vehicle, and potentially to take on some of the functions of a CAM or to serve as a CAM themselves.
- Understand the growing trend in the AV industry toward the development of AV software modules. Some companies are developing AV software platforms that can be ported to the OEM AV vehicle (hardware) platforms, relieving each individual OEM from having to develop their own AV control software. Several major OEMs have begun prototyping with such third-party AV software platforms. Conversations could be initiated around the development of a standardized RUC module that could be ported similarly to multiple AV software platforms. Such an approach could achieve significant reductions in complexity and cost for achieving trusted source certification.

[25] States would need to update RUC specifications to support the OEMplus concept in addition to the standard CAM model. The OEMPlus or self-aggregated data would need to be based on measurement or calculation of miles traveled from raw data and should be correlated to odometer data periodically for each vehicle, to ensure that it is being calculated correctly.

3.2 Convenience/Usability

Positive interactions between a potential RUC system and its users promote adoption and compliance. Many RUC pilots have shown that having a positive user experience with RUC is vital to the success of RUC as a policy. The user experience with RUC can always be improved. AV end users and fleets create new cases for convenience, usability, and choice explored in this project.

3.2.1 Minimize the Burden on Fleets Through Improved User Experience

Pilot Findings

- AV vendors like Udelv will not want to spend much time or effort enrolling with a CAM and reporting their RUC data. It is likely that most AV users for the foreseeable future will be fleets, so CAM functionality will need to support fleet interfaces and provide the most effortless RUC experience possible.
- Fleet operators operate in a complex regulatory environment. Fleet owners are already overwhelmed with operational and administrative requirements and will not welcome more complexity. Fleet owners expressed frustrations over complexity and poor user experience of tax reporting systems.

Recommendations

- Create a set of user experience (UX) requirements or guidelines. These requirements or guidelines should specify CAM functionality, be user-friendly, and provide fleets an interface designed for their needs, not simply an unmodified or slightly modified version of the private user interface. Thus, UX requirements should be suitable both to private and commercial vehicle users including vehicle fleets, which are likely to make up a significant portion of AVs. Some, if not all, CAMs should be required to have a specific fleet interface.
- Gain better understanding about who the fleet users will be and what their workflows will involve to identify their commonalities and differences at key touchpoints like onboarding, integration, invoicing, and payment. Having such insight offers the opportunity to integrate touchpoints into fleets' existing operations, minimizing the time and effort they spend on compliance.
- Look for further opportunities to integrate RUC data into existing fleet management software,[26] because it would circumvent the need for fleet owners to monitor a separate dashboard (a new touchpoint introduced for Udelv, which had its own separate fleet tracking system). It has the potential to introduce such efficiencies as:
  - Automating enrollment by using the software's existing bank of vehicles
  - Seeing RUC data in real time to help track operating costs
  - Sharing reports between fleet managers and their relevant stakeholders

[26] For example, existing telematics providers have done this with RUC in Europe, New Zealand, and Oregon.

Pilot Findings continued

- Fleet operators appreciate the "invisibility" of the gas tax. Any replacement tax should have minimal touchpoints and prioritize simplicity while still allowing fleets to track their operational costs efficiently. In the discovery phase, the team heard that tracking RUC data would not be worth the labor for a fleet owner. During research, fleets indicated that even if RUC were a hidden tax like the gas tax is today, tracking would still be necessary for firms that manage costs at a granular level, especially if they intend to pass off those costs to their customers.

Recommendations continued

- Expand beyond opportunities to design a user-friendly RUC for AV fleets. Further integration with fleet management services is desirable to help fleet vendors understand, predict, and plan around RUC costs anytime. For example, states could provide the following opportunities:
  - Use publicly available geofences, digital maps, and tax rates to forecast RUC charges.
  - Enable integration of CAM invoices and automatically check for anomalies against vendor data.
  - Enable multiple users to access the data for their operational needs.
  - Provide various RUC reports that are heavy with information to accommodate any finance teams tracking process and operational needs.
  - Provide easy access to and export of needed data.

3.2.2 Support User Choice

Pilot Findings

- One size will not fill all. Business structures and capabilities vary widely. The pilot revealed that assumptions cannot be made about the capabilities or resources a business might have to accommodate standardization and accurate reporting. The sampling of fleet managers had vastly different operational needs and may benefit from a variety of service offerings to report RUC.[27]

Recommendations

- No new service model should rely on AV fleet operators' presumed institutional knowledge, role responsibilities, capabilities, or resources on-site.
- States should discuss both the standard CAM and the OEMPlus concept with OEMs and fleet management service providers to provide more choices to businesses operating AVs (and eventually private AV owners).
- Observe the market as it develops and allow RUC policymakers to respond accordingly to address both business and individual owners' needs. Unless all OEMs are certified to offer data aggregation as a trusted source, a separate certified CAM will be needed to provide RUC data in appropriate format and funds (payments) for all vehicles subject to RUC. CAMs will be needed in the foreseeable future for the following reasons:
    - Legacy vehicles produced without telematics capabilities will likely be part of vehicle fleets albeit in decreasing numbers compared to the current situation.
    - Some AV vendors may not want to perform data aggregation and will simply find it easier to use separate CAM services.
    - It would be undesirable for states to perform data aggregation themselves (even if they had the technical capabilities) for privacy and commercial confidentiality reasons. However, some states may wish to have a state account manager or "white label" a CAM's work, legally acting as a CAM but using a private CAM's underlying technology.

[27] Sample consisted of two fleet operators, one OEM/fleet manager, and two fleet management software providers.

3.3 Explore Opportunities to Reduce Cost of Collection

One of the biggest concerns about RUC today is the cost of RUC collection. One of the key questions researched was whether the connectivity, advanced computation, or mapping capabilities of AVs could eventually be leveraged to lower data processing and data mapping costs for RUC.

3.3.1 Leverage Connectivity

Ubiquitous, fully automated vehicle operation is still years in the future, but partially automated operation already exists and will become increasingly common in the next few years. Vehicles capable of partially automated operation will all be CVs. Some categories of vehicle operation will use partial automation faster than others (urban delivery and long-haul freights are likely to begin using partial automation sooner than other categories).

Pilot Findings

- Data provided by Udelv were simply vehicle identification data, vehicle location data, and distance data. These data are general vehicle data that would already be collected by systems in CVs.
- CV data are more relevant than AV data. No data or technology required for RUC are unique to AVs. In fact, AVs do not need any of the data elements required by RUC to function in an automated mode. For at least the next 10 years, CVs will outnumber highly automated vehicles (Levels 4 and 5).
- CVs are already numerous and their numbers are growing rapidly, while there are unlikely to be highly automated vehicles (Levels 4 and 5) in substantial commercial production for at least five years, and their numbers will remain small for some years after they are introduced.

Recommendations

- Further research RUC and standardize work to prioritize leveraging CV technology, with AVs as a subcategory of CVs. Telematics/V2N should be the focus of all RUC policymaking on CVs for the next few years. While direct communications (including V2V, V2I, V2P) could have desirable properties for RUC spot enforcement functions, its key limitation is its reliance on additional network or infrastructure. Thus, RUC policy should only consider incorporating direct communications if it is on a path to widespread deployment.
- Establish standards for RUC data collection from CVs as rapidly as feasible so players in the CV ecosystem are prepared to provide this data as rapidly as possible.
- Standardize data interface between AVs and the CAM, and perhaps between the CAM and RUC payee/agency. Data security and privacy protection can be specified in those standards to provide a pathway toward commercial implementation. In addition, an AV operator may want to optimize when it travels and the base route selection on variations in pricing related to where and when it drives. This information is needed prior to a trip and could be standardized on the interface between the CAM and RUC payee, and between the CAM and AV operator.

3.3.2 Mapping & Self-Aggregation Capabilities

AVs and CVs already have the technology onboard to track their location and recognize when they have entered a certain geographic area. According to the OEMPlus concept, OEMs could enable vehicles to load boundaries for these pricing zones as geofences on AVs, or to apply charges to digital maps by road (and separate on-road from off-road distance traveled), and the vehicle systems can easily count the number of miles driven in each zone.

This architecture would be similar to the thick client concept used in telematics OBUs in Europe in the 2000s, in which the OBU has an application-processing capacity and processes everything onboard. The OBU would have a MapInfo mapping interface that contains maps and builds toll/tax transactions on its own. The main issue was that maps needed to be updated for roads to be identified as public roads so that off-road distance could be excluded. As AVs have advanced mapping capabilities and need up-to-date maps to function, this concept could be more feasible for AVs.

Pilot Findings

- The pilot did not allow demonstration of the full OEMPlus concept simulated by Udelv. Mapping GPS data generated by the AV to geofences would have required too much development effort for Udelv without adding any value to their main business focus, which is automating delivery (and not reporting data).

Recommendations

- Continue investigating data aggregation by the vehicles themselves by having conversations with those who influence the design of the vehicle telematics systems that can support RUC and self-aggregation.
- Invite OEMs, at a minimum, to the table when working out the systems around RUC data collection and payments. The ownership structure could impact who the main players are in RUC collection. Commercialization of AVs, including ownership, and which entities will drive production and demand, is currently not possible to predict. Regardless of whether this is driven by individual AV owners or fleet AV operators, the greatest impact and influence on the integration of in-vehicle RUC systems will be the OEMs. If AV firms remain separate from OEMs, they should be engaged as well. RUC should be facilitated by the highest in the manufacturing order (ideally OEMs). States should consider this and engage stakeholders at the highest level possible.
- Build relationships between states and smaller startups that are mostly developing specialized AVs for transit and delivery. Working with these smaller startups will likely be very different from working with the larger, traditional OEMs that are expected to produce most of automated passenger vehicles.

3.4 User Acceptance

Policy implementations can fail due to lack of user acceptance; therefore, it is important to understand acceptance factors for different categories of users in the early phases of engagement. The project presented the opportunity to interface with a new category of stakeholders to get them acquainted with the RUC concept and gauge their level of understanding and acceptance of RUC policy. These engagements emphasized the importance of clearly articulating the benefits of RUC and devising simple rules at the outset to avoid imposing administrative burdens on businesses.

3.4.1 Communicate RUC Benefits and Avoid Targeting Automated Vehicles

Pilot Findings

- The degree of familiarity with RUC varied across AV stakeholders. Many AV stakeholders were not familiar with RUC and the funding problem it seeks to solve.
- AV stakeholders are willing to pay a RUC that applies to all vehicles, but they do not want to pay any fees that apply to AVs only.
- Additional research revealed that the Eno Center for Transportation proposed fees that applied to AVs, and this proposal was introduced in the legislatures of Massachusetts and Tennessee. AV firms do not like this legislation. They understand the need for RUC and are willing to support RUC efforts, so long as AVs are not singled out for specific fees. If specific infrastructure improvements are ever needed to support and promote AVs that states wish to fund, then AV firms may be convinced of the merits of charging a fee for the use of such infrastructure. However, the need for such infrastructure is not yet established.

Recommendations

- Avoid AV-specific fees for the near term. The case for such fees should be demonstrated based on economic evaluation.
- Engage states with AV stakeholders (and new transport and mobility players in general) to raise awareness on RUC, what it covers, how it works, and where AV stakeholders fit in the bigger picture. It is important to clear any misperception that RUC targets AVs specifically and explain that RUC revenue is used to improve road infrastructure.
- Base the fee setting for RUC on sound economic principles around allocation of road infrastructure costs to road users. Any additional fees should reflect such principles.
- Leverage RUC data to build positive engagement when faced with inevitable skepticism about RUC. Opportunities include the following examples:
  - Use visualization to contextualize a user's data in a way that informs them how their RUC activity is improving infrastructure.
  - In exchange for infrastructure and traffic monitoring, some states could choose to offer reduced RUC rates or personalized data about a vendor's positive impact that they can use for marketing. These opportunities areas are documented in Section 5.1 – Northstar Concepts.

3.4.2 Simplify Rules

Pilot Findings

- AV vendors want a single, simple set of rules for operation in all states.
- Eventually, AV vendors will want their vehicles to work in neighboring countries, though that is outside the scope of this project's recommendations.

Recommendations

- Work with RUC organizations and other states, and potentially the federal government, to establish a single set of RUC rules.
- Have states seek opportunities to eliminate redundancy with other taxes by looking for policy synergies and prioritizing interstate operability.
- Work to establish a single set of high-level RUC reporting rules among RUC West states and other U.S. states. Such a set of rules will need flexibility to allow states to have their own custom features, such as reporting methods, RUC caps, discounts and exemption, and other features unique to states. Ideally, there will be one set of high-level reporting rules by which miles by state by VIN is captured in a standard process. These rules should accommodate both the standard CAM model and the OEMPlus concept. Further, these rules should accommodate interoperability rules. The OEMPlus concept in particular will need to remit funds and data to multiple states.

This section presents possible future AV scenarios in three different categories: connectivity, AV ownership model, and categories of AV. It then covers potential timelines to develop combined RUC/AV policies based on advancement of AV technology and AV-impacting policies implemented by states.

4.1 Automated Vehicle Scenarios

Connectivity

Connectivity refers to how vehicles communicate, transmit, and receive data. The fundamental ability to send and receive data is a more significant factor for the approach of how to incorporate the vehicles into RUC than the automated nature of vehicles. CVs, as well as AVs, can automatically communicate data relevant to RUC, such as location, distance traveled, and supplemental vehicular data. Note that all AVs are CVs, but not all CVs are AVs. However, for the purpose of implementing RUC systems, it may be desirable to focus technical and policy approaches on CVs and treat AVs as a subset of CVs. This approach will allow policymakers to achieve significant impacts more rapidly, rather than waiting for widespread AV deployment, because CVs will be more widespread for the foreseeable future.

There are two basic models for vehicular connectivity: telematics/V2N and direct communications. These models have the following characteristics:

1. Telematics, or V2N, refers to communications via a broadband backhaul provided by the OEM. This means one or more cellular modems in vehicles communicate data via a smartphone network, which is the standard form of connectivity in all telematics-enabled vehicles today. The bandwidth feasible via telematics/V2N is increasing, most notably, through the increasing deployment of fifth-generation (5G) cellular equipment.

2. Direct communications (including V2V, V2I, V2P, and others) refers to direct point-to-point radio communications between vehicles and other vehicles or infrastructure. Such connectivity has a substantially lower latency (communications delay) than telematics/V2N. This low latency could allow equipped vehicles to take sudden maneuvers to avoid collisions, so it is intended first for such safety applications. However, direct communications can be used for other applications as well, and preparations are being made for this possibility. Such communications have been tested in a variety of programs over the past 15 years but have not yet been widely deployed by carmakers. When carmakers deploy direct communications, they could have desirable properties for RUC audit and enforcement functions. The key limitation of this technology is that it is dependent on an additional network of infrastructure or on the use of such systems for packet-based communications between vehicles until, ultimately, data can be communicated by other infrastructure to back-office systems.

Automated Vehicle Ownership Models

AV ownership may take on several models, and the future most likely would involve a combination of these models. The potential ownership models are as follows:

1. **OEM ownership –** In this model, the OEM itself retains ownership of the vehicle. OEMs would earn revenue from the vehicle end users, which could take on two forms: single use via app or medium-term use via a contract.
2. **AV provider ownership –** AV providers are third-party developers of AV sensor and driving intelligence that take nonautomated OEM equipment and automate it. Udelv's second-generation Level 4 vehicle, for example, uses the Ford Transit chassis. Other AV providers include Waymo, Argo, and Cruise (the latter of which is a wholly owned subsidiary of GM). OEMs may absorb such firms, because their technology is commoditized, but they may also remain independent of OEMs. If they do remain independent, they could own the AVs, and like OEMs, earn funds from the use of a vehicle from the end users through a variety of methods.
3. **Fleet ownership –** Vehicle fleets could own or lease their AVs. This could range among large shipping fleets for large retailers, freight carriers, fleets of robotaxis from ride-hailing companies, and meal delivery services. Many of these companies currently contract private individuals, but AVs could change this dynamic if their use helps these companies reduce their operational costs.
4. **Private ownership –** Some AVs may be owned privately, but this may be the least likely scenario in the near-term because of their prohibitive costs and safety or insurance requirements.

It is uncertain who will eventually be primary owners of AVs (fleet operators, AV companies, or OEMs). It is possible that some mixture of all of these ownership models will emerge, depending on cost and demand.

Categories of Automated Vehicles

AVs are likely to come in many different models, serving different market needs. There could be a greater variety of AVs than conventional vehicles, because the absence of need to support a human driver allows the vehicle to take a variety of forms not feasible when a human driver is needed. Many other categories of AVs may emerge. For now, the following main categories of AVs are expected:

1. **Urban delivery**, including vehicles that deliver goods to end users. This includes the following subcategories, each of which may be impacted differently by RUC:
   a. Small delivery drones that operate on the road or sidewalk
   b. Medium delivery vehicles that deliver goods to homes and businesses and are likely to operate only on roads
   c. Large business-to-business delivery vehicles that deliver goods to stores and may include medium-duty vehicles
2. **Robotaxi passenger vehicles** that will vary in occupancy.
3. **Private AVs**, which are likely to spend a good portion of the day parked.
4. **Long-distance freight vehicles** that are likely to be heavy vehicles. As such vehicles emerge over the coming decade, it is most likely that they will operate in a Level 4 manner on rural freeways but need to be operated by a human driver (in Level 2+ manner) in urban areas.

4.2 Automated Vehicle's Technical Capacity to Support Other Fee Structures

The discussion of whether to incorporate additional fees, such as parking fees or congestion pricing, is highly political and shaped by the unique political, cultural, and administrative structures of each state. This report makes no recommendation on the policy decision as to whether other fees structures should be supported in a RUC structure. However, in the context of this study examining issues for AVs, it is worthwhile to comment on the potential technical feasibility of combining various fees.

AVs may use the transportation system differently and, therefore, could affect traffic in unique ways. Depending on how this develops, states could ask the question of whether other fee types could be beneficial, such as deadheading fees (fees for driving empty), curb space or loading fees, (which are, in essence, a form of parking fees), or congestion charging. The pilot project with Udelv did not explore such fees, but it could be studied as AVs become more common. States might think about combining such fees with a RUC structure to simplify administration and potentially reduce costs for the state, providing a less burdensome experience for AV fleet businesses. This project addressed these policies not in the RUC pilot directly, but in the scenario-based research that AV stakeholders engaged in during concept generation workshops and interviews.

RUC may impact different categories of AVs in different ways. States might consider different charging rates depending on how much damage they impose on the roadway(s) on which they are licensed to operate. Technically speaking, time- and/or location-specific fees may be applied to them. The same principles also apply to all vehicles.

Recommendations

- AVs can technically support other potential fees such as congestion charges, curb fees, deadhead charges, or local RUC added on to a RUC structure, bearing in mind that privacy concerns would still apply.
- For AVs to efficiently process these fees, states would need to ensure that RUC specifications include a means of informing the CAM and/or AV operators with the variable pricing information (geographical representations of pricing tiers with fees based on time-of-day tables related to congestion upcharges, parking zones, etc.).
- For AVs to reliably process these fees, states would need to develop standards that specify the interface between CAM and AVs, and between CAM and the RUC payee. This would facilitate the sharing of these route or geofence and time-of-day tables that inform the users/operators of the incurred charges per mile.

4.3 Possible Timelines for Mobility Policy

Table 5 illustrates the progress over the next 20 years. For each block of five years, the chart illustrates the AV technology expected to be available, some possible AV-impacting policies that states may be pursuing at this time, and the specific RUC/AV policies that states can pursue, as determined by the project team. Note that the second category, "possible AV-impacting policies that states may pursue," are not AV policy recommendations for states but the Collective Impact Team's best understanding of how states may be proceeding. It is included only as a reference point for the RUC/AV policies that states can pursue. The final category was directly determined by the project team.

Table 5: Future 20-Year Progress

Year	AV Technology Expected to be Available	Possible AV-Impacting Policies that States may Pursue	RUC/AV Policies that States can Pursue
2021–2025	■ Level 1 widely available ■ Level 2+ available on high-end vehicles ■ Level 4 in test operation and extremely limited revenue operations	■ Support AV testing ■ Develop policies for Level 4 operations by category (urban delivery, freight, etc.) ■ Research potential infrastructure for Level 4 AVs	■ Develop and refine RUC for AV open standards
2026–2030	■ Level 2+ widely available ■ Level 4 in limited revenue operations	■ Implement Level 4 operations policies ■ Implement Level 4 infrastructure, if needed	■ Bring interoperability solutions for RUC/AV online ■ Research additional RUC/AV policies in light of Level 4 rollout, and update standards if needed
2031–2035	■ Level 4 in ever-broadening revenue operations	■ Refine Level 4 operational policies based on experience	■ Research additional RUC/AV policies in light of Level 4 rollout, and update standards if needed
2036–2040	■ L4 in widespread revenue operations ■ L5 in initial test operations	■ Develop Level 5 operational policies, to the extent that they differ from Level 4	■ Research additional RUC/AV policies in light of Level 5 rollout, and update standards if needed

Recommendations on Timing to Develop Combined RUC/AV Policies

- During the first stage, now through 2025, Level 2+ vehicles, such as vehicles with GM's Supercruise, are becoming more widely available. These automated driving assistance systems (ADAS) vehicles are easier to develop than vehicles that can operate in fully automated mode (Level 4/Level 5 vehicles). The machine learning needed for Level 4 is extremely difficult and still under development, but it is showing promise on rural freeways. Urban automation is much more difficult, so aside from small robotaxi deployments, like Waymo's Phoenix deployment, urban automation is likely to remain in test mode during this period. At this time, states can still develop Level 4 policies while their deployment remains isolated. In the context of RUC, states can develop and refine open standards to support RUC for commercial vehicles (and AVs).
- During the second stage, 2026 through 2030, Level 4 vehicles slowly begin to enter limited revenue operations. States need to implement Level 4 operations policies to allow this and implement any infrastructure deemed necessary to support Level 4 vehicles. In the context of RUC, states should bring solutions for RUC interoperability online and potentially research additional charging policies that may be needed in light of the Level 4 rollout.
- During the third stage, 2031 through 2035, Level 4 vehicles will be operating in ever-broadening revenue operations. States will be refining their Level 4 operational policies as this occurs. In the context of RUC, states should keep refining their charging policies to capture externalities AVs (and other vehicles) might impose.
- During the fourth stage, 2036 through 2040, Level 4 vehicles will be operating in widespread revenue operations, and Level 5 vehicles will emerge. States will develop Level 5 operational policies to the extent that they differ from Level 4. In the context of RUC, states should develop any additional charging policies that may be needed for Level 5 vehicles.

This section provides some forward-looking concepts, or Northstar ideas, for further exploration. These ideas are based on best estimates of where technology, industry/business, and government are heading using the latest information available to the team. The future is unknown, and neither industry nor technology follow a linear path. Thus, the Northstar ideas documented are inherently speculative. Furthermore, options to support reduced fees or allow partial payments are presented as opportunities for states to leverage RUC data to build positive engagement with AV stakeholders. It will be up to each state to determine how these opportunities could be relevant to their unique environments.

5.1 Northstar Concepts

Building on the OEMPlus RUC Process Flow designed with AV stakeholders and the three opportunity areas—maintain convenience, leverage AV technology, and protect privacy for AV fleet operators—as guiding principles, the team generated five forward-looking RUC scenarios, or Northstar concepts. These Northstar concepts are based on the five- to 10-year time frame.

5.1.1 Automated Vehicle Fleet Owners Share Data to Reduce RUC

By 2035, 10% to 15% of vehicles on the roads may be automated, with fleet operators making up more than 60% of those AVs. Some fleet operators may decline to share their data for privacy and commercial confidentiality reasons, while others may choose to share data to reduce their overall cost of doing business. This choice provides greater financial flexibility in the market. Some AV fleet operators could choose to supply real-time data directly to cities as partial payment for their RUC. For example, leveraging the Mobility Data Specification created by the Open Mobility Foundations, AVs send useful data like travel times, pothole detection, inclement weather, or vehicle collisions to municipalities. In exchange, fleet owners' RUC is discounted in the areas they are monitoring. CAMs may apply discounted rates for zones where a fleet operator agrees to supply data, while the remaining zones are charged at the normal rate.

5.1.2 Commercial Account Manager Prepays RUC

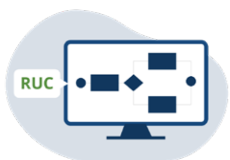
CAMs are mileage brokers between the state and the fleet owner, similar to the way fuel vendors pre-pay fuel taxes today. The CAM maintains an inventory of "wholesale" miles (i.e., units of RUC) purchased in bulk at a discounted rate from state governments. Fleet owners pay their CAM for the miles they have used at a "retail" rate. Monthly, the CAM replenishes its coffer with more miles from states. This regular cycle of cash flow preserves the benefits of early payment to states without burdening fleet owners with up-front costs, while CAMs earn a regular income from the resale. Auditing would ensure fleet operators are not paying more for the road utility than they would have otherwise.

5.1.3 Automated Vehicle RUC Counter

States provide OEMs with geographic boundaries for RUC zones, and the OEM enables the vehicle (as a trusted source) to determine the number of miles driven in each of them and to calculate the applicable RUC rate (this is the OEMPlus concept). OEMs confirm the payment of RUC charges simply by resetting the RUC counter on the vehicle once payment has been made. States (or their agents) can be provided with a key (e.g., certificate) that the vehicle can validate. When the key is presented, the vehicle will communicate the number of miles driven by RUC zone and prompt for a reset code. The state authorizes the reset, and said miles are removed from the vehicle's counter. This concept could eventually be enabled by technologies such as distributed ledger technology.

5.1.4 Original Equipment Manufacturer Finance Companies Service Road Usage Charges

Financial companies associated with an automotive OEM leverage their existing relationship with states in which they operate to facilitate the collection of RUC from their customers. With vehicles collecting usage data including location, the financial divisions use maps authorized by the state to calculate the payments for states and use their existing banking connections to transfer the funds. By managing this relationship, RUC is added into a monthly payment on a vehicle or covered by the OEM as an incentive to new buyers.



5.1.5 Actionable Insights for Fleet Operators Provided Directly by Original Equipment Manufacturers

OEMs provide fleet operators with metrics that can be used in Enterprise Resource Planning applications and/or the operator's proprietary software to optimize their business. Through managing the RUC, the OEM can identify the cost of a trip and provide a metric that reflects the relative cost of doing business for each of the operator's clients. While map service providers like Google will be able to predict the cost of a specific trip, the OEMs can be a trusted provider for the operator, aggregating their specific activities over time. These active metrics can be made available to the fleet operator securely in the cloud where the operator can incorporate them into business process management rules.

Note: This service is already provided by fleet management software providers. The idea is for OEMs to integrate these in their native telematics packages.

5.1.6 Evaluation Method of Northstar Concepts

The Northstar concepts were evaluated against the three key insights from the concept generation workshop using the rubric in Figure 18. Workshop participants selected high-ranking concepts across all three categories as providing the highest benefits.

	AV fleet owners share data to reduce their RUC	CAM prepays RUC	Automated vehicle RUC counter	OEM finance companies service RUC	Actionable insights for fleet operators
CONVENIENCE	● ● ○	● ● ○	● ● ●	● ● ●	○ ○ ○
AV TECHNOLOGY	● ● ○	○ ○ ○	● ○ ○	○ ○ ○	● ● ○
PRIVACY	● ○ ○	● ● ○	● ● ●	● ● ●	● ● ○

Figure 18: Discovery Phase Workshop Rubric

These Northstar concepts eventually could be researched further and piloted with OEMs and fleet management solution providers.

5.2 Vehicle Original Equipment Manufacturer Cooperation in Road Usage Charge

Vehicle OEMs have already begun to outfit vehicles with the necessary technology for RUC, although they have done so for other reasons. For example, new vehicles now have one or more mechanisms to communicate with the OEM—primarily through cellular communications to the OEM's cloud service—and transmit basic telematics data of position, speed, and vehicle safety alerts and diagnostics. Other services that offer over-the-air (OTA) updates are also becoming more common, enabling OEMs to update vehicle-based software remotely, including apps within the infotainment system or even vehicle control functions. Vehicle OEMs have also begun to deploy more ADAS into vehicles, which can warn a driver of certain conditions, such as lane departure or a collision risk, and in some cases take control of throttle, braking, or partial control of steering. These are often referred to within the SAE Levels of Automation as Levels 1 through 3. These ADAS systems could play a role in RUC in that certain ADAS features may need access to the same vehicle data that would be needed for RUC, such as position, speed, and even date/time values.

The combination of these systems—external communications and internal sensing—are the basic ingredients for enabling RUC. These would then need to be combined with a "RUC app or module" (or RUC piece of software) that resides on the vehicle itself, which can send and receive information with an external "RUC authority" and gather, clean, and log internal vehicle state data. Rules of the RUC app would govern these external and internal functions, which may be updated via OTA communications. An app would determine when RUC is in effect and potentially determine details such as pricing, opt-in/opt-out availability, etc. A RUC app or module could also interface with navigation apps if, for example, a driver wanted to select a route that minimized RUC charges or avoided RUC roadways or regions altogether. The software for this type of app and the vehicle-based sensors that would be accessed would also need to be secured within the vehicle such that physical and electronic tampering is prevented. Rules should also be adopted to safeguard personally identifiable information. These capabilities should be coordinated through standards bodies or industry consortia to ensure interoperability among OEM vehicles.

Vehicle OEMs have already begun to lay the groundwork for RUC implementation, and the next steps should include a broader coalition for standardizing communication protocols, security measures, data (type/format/latency/frequency), financial transactions, and enforcement.

5.3 Road Usage Charge Using Distributed Ledger Technologies

Distributed ledger technology (DLT) has emerged as a potentially revolutionary approach across a variety of industries, including transportation, banking and financial, logistics, and supply-chain management. DLT provides a mechanism for enabling peer-to-peer transactions and maintaining records in an immutable form that is distributed across a system of nodes, which is auditable by anyone. Similar to other decentralized systems, there is no single point of failure where a successful attack might compromise the entire system, so DLT provides inherent security against such attacks, as well as the capability to self-heal when part of the system is damaged, lost, or otherwise compromised. The term "blockchain" is often used as a generic term to encapsulate all DLT; however, a blockchain is only one way in which the transactions in a distributed ledger can be organized.

Transportation systems are changing rapidly with the introduction of new technologies and modes of operation, including CVs, AVs, shared mobility services, and vehicle electrification. These are providing a unique opportunity for the deployment of DLT as a means for establishing transactional relationships among devices (nodes) that may or may not have an existing trust relationship. One concept in DLT is that of the *Smart Contract*, which essentially is a secure multiparty workflow where the parties need to assert the existence of transactions, cash flow, data, violations, etc.

Similarly, DLT has been proposed for use in CV systems as a secure mechanism for commercial vehicles to transact certain types of data or agreements. The application of RUC using DLT would enable vehicles to negotiate directly with infrastructure devices to execute smart contracts that exchange money, credits, or other units of value for the right to use a section of roadway, or for rights of use for an entire region.

As DLT emerges as a viable technology for a variety of applications, states could work to explore a DLT solution that allows trusted integration of different rule sets for each region, state, or city.

What is a Distributed Ledger Technology (DLT) and how is it related to blockchain?

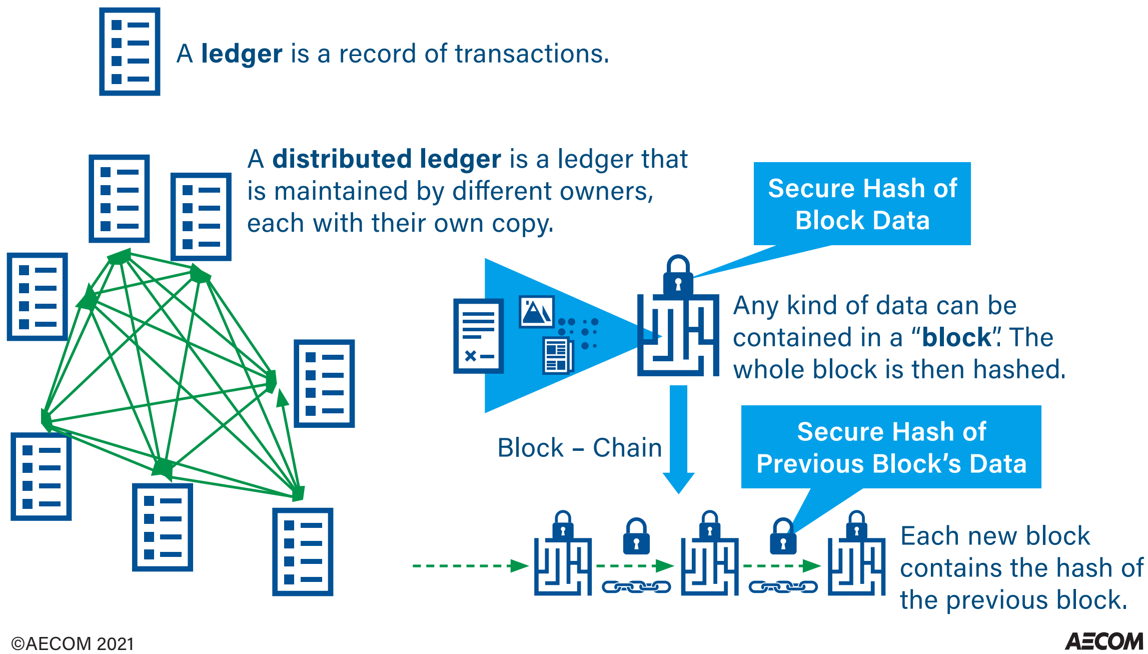


Figure 19: DLT Overview

Conclusion

Cooperation between participating states and private-sector involvement are characteristic of RUC West research efforts. The Collective Impact Team embodied this approach by involving experts and AV stakeholders across the industry in the creation of vendor-agnostic and forward-looking revenue solutions that leverage open standards and technology advancements.

This project demonstrated the value of states engaging AV stakeholders in a constructive dialogue to understand their technical capabilities, operational constraints, and concerns. Stakeholder engagements provided insights into how various industry segments are considering transportation revenue policy options, especially RUC. They revealed that RUC reporting capabilities vary widely and requesting businesses operating AVs to set up data exchange interfaces to support RUC may not be a trivial ask. Interactions with fleet operators highlighted the fact that they already operate in a complex regulatory environment. The complexity of their operating environment underscores the importance of improving usability and convenience aspects of RUC systems specifically for fleet and AV businesses. Doing so should promote their acceptance, adoption, and compliance with RUC policy.

The Collective Impact Team encourages states to work with standards bodies to create RUC processing and data exchange standards. Further, states should engage with OEMs and fleet management services as much as practicable to ensure these standards emerge and can be made accessible to businesses operating AVs without requiring additional investments.

In parallel, states should continue engaging with AV stakeholders and OEMs to explore opportunities to leverage CV technology and AV technology in the development of a standardized RUC software module. Such a RUC software module could be integrated to AV platforms to achieve trusted source certification in a simple and cost-effective manner.

Standards Background

SAE J3217 is the name of the SAE standard being developed to support direct vehicle-to-infrastructure-based toll payments. In 2022, the standard will be expanded to include specifications for a RUC message set. This will enable RUC payments not based on direct vehicle infrastructure transactions and will support telematics and other cellular, communications-based tolling. The standards are developed with input from automotive OEMs and infrastructure owners and operators. The RUC aspect of J3217 will likely be complete in 2022.

OmniAir is developing a certification program to certify compliance to the standard defined in J3217. OmniAir is an industry trade association dedicated to certification of intelligent transportation equipment including CV and tolling equipment. OmniAir's is an ongoing effort to develop a certification program for the full value chain of a tolling transaction. Proper certifications require standards. Not all aspects of the tolling transaction have standards yet, so the OmniAir team is prioritizing the parts of the certification program that already have standards.

There are currently three main groups supporting the effort, including:

- **J3217 –** This group is developing a program to certify compliance to J3217.
- **Outreach –** This group is considering the input necessary from industry and deployers to get thorough stakeholder engagement.
- **Telematics/Cellular –** Since there are no standards for cellular tolling/RUC, this team is analyzing adjacent standards and other approaches for beginning a certification program for an area where there are not any standards yet.

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