NEW PATHS TO ROAD FUNDING

rucwest.org

RUC WEST TECHNOLOGIES FOR RUC COMMUNICATIONS

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prepared for

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prepared by

D'Artagnan Consulting, LLP

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Revision History

Name of Person Responsible for Change	Date of Revision	Reason for Change and Short Summary of Revisions Made	Version Number
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Glossary

The meanings of project specific terms and abbreviations used in this document are given in the following table.

Term	Definition
AES	Advanced Encryption Standard
AI	Artificial Intelligence
ANPR	Automatic Number Plate Recognition. Technology to identify vehicles based on video technology to read their number plates and match that number to a database of vehicle owners.
Area Charge	Charging vehicles for crossing a boundary of an enclosed area or driving within that area at specific times of days, typically to manage demand. For example, London's Congestion Charge is an area charge.
CAN-BUS	Controller Area Network: vehicle bus (i.e. a specialized internal communications network that interconnects components inside a vehicle) standard designed to allow microcontrollers and devices to communicate with each other in apps without a host computer
Congestion Charging	Charging vehicles for use of specific roads during specific times and days, in order to reduce the severity and duration of congestion on the network. Revenues from such charging are not necessarily linked to any road or transport infrastructure costs.
Cordon Pricing	Charging vehicles for crossing one or more charge points across a series of roads at specific times of day, typically to manage demand. Cordon pricing does not charge for traffic movements within the cordon. Stockholm's congestion tax is a cordon.
Corridor Charging	Charging vehicles to use all of the roads in a corridor (main highway and secondary routes).
CV	Connected Vehicles
DC	Data Collection
DSRC	Dedicated Short Range Communications. Used in Europe for tag and beacon road charging, whereby a small battery powered device is installed in a vehicle to enable identification in a toll system. In the US, DSRC is the accepted standard for safety-sensitive Connected Vehicle applications due to its very low latency.
ECOTAXE	ECOTAXE was a GNSS-based distance charging system applied for trucks 3.5 metric tons (~7,700 lbs.) or more in France. It was halted soon after its implementation in 2014.
ECU	Engine Control Unit
EPA	Environmental Protection Agency
ERP	Electronic Road Pricing – the congestion pricing system operational in Singapore
Eurovignette	The Eurovignette is a common system to charge and control road user charges in Denmark, Luxemburg, the Netherlands and Sweden. The vignette applies to HGVs with a total permissible weight of more than 12 metric tons (~26,500 lbs.) on motorways and selected roads. The electronic Eurovignette replaced the paper-based vignette system on 1st October 2008.
FIPS	Federal Information Processing Standard, which includes two-digit numerical codes for each U.S. state/territory.
FCC	Federal Communications Commission
Free-Flow Tolling, Open Road Tolling	Free-flow or Open Road Tolling systems are based on the electronic collection of tolls on toll roads without the use of toll booths.
GALILEO	European Union GNSS system
GIS	Geographic Information System

Term	Definition
GLONASS	Russian GNSS system
GM	General Motors
GNSS	Global Navigation Satellite System. A generic term for such systems which includes GPS, GALILEO and GLONASS
GSM	Global System for Mobile Communications (GSM)
GPRS	General Packet Radio Service (GPRS) is a packet oriented mobile data service on the 2G/3G cellular communication system's global system for mobile communications (GSM). It supports a download speed of up to 114 Kbps
GPS	Global Positioning System
Heavy Good Vehicles (HGV)	European designation for trucks with a gross combination mass of up to 3.5 metric tons (~7,700 lbs.)
Heavy Vehicles	Vehicles 10,000 lbs. and over – typically rigid and articulated trucks and buses as well as special purpose vehicles such as cranes.
HTTP	HyperText Transfer Protocol
IFTA	International Fuel Tax Agreement
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
Light Vehicles	Vehicles less than 10,000 lbs., including both passenger cars and light commercial vehicles.
LKW-Maut	"Lastkraftwagen-Maut" or heavy goods vehicle toll. The German heavy goods vehicle distance-based road charging system that has been in operation since 2005 using GNSS technology.
Mileage Meter	A mileage meter is an app, device, or inbuilt system that collects road usage charge information for the vehicle in which it is installed
MM	Mileage Meter (see MRD)
MRD	Mileage Reporting Devices (see Mileage Meter)
OBDII	On Board Diagnostic specification version 2
OReGO	OReGO is the Oregon Department of Transportation's Road Usage Charge program
PAC	Project Advisory Committee of the RUC West Technology for Road Usage Charge Communications – An Inventory of Devices project.
PII	Personally Identifiable Information
Pilot Participant	Pilot Participants are volunteers recruited to participate in Road Usage Charge pilot projects.
Project	The RUC West Technology for Road Usage Charge Communications – An Inventory of Devices project.
Road Charging	Direct charging of road users for the use of the road network, distinct from tolls in that charging is not applied to a single part of the network to recover the infrastructure costs for that part of the network.
RCPP	Road Charge Pilot Program (California)
RFID	Radio Frequency Identification (RFID) is a wireless technology which uses Radio Frequencies (between 30 kHz and 2.5GHz) to automatically identify objects remotely
RUC	Road Usage Charge
RUC Payer	The motorist or driver responsible for paying RUC charges incurred by his/her vehicle
RUCPP	Road Usage Charge Pilot Program (Oregon)

Term	Definition
RUC West	RUC West is a consortium of western U.S. states that brings together leaders from state transportation organizations to share best practices and research Road Usage Charging.
Toll / Toll roads	Direct user charges in the form of regulated, facility-based tolls for usage of specific road corridors.
Toll lanes	One or more lanes on a highway that may only be accessed by paying a toll, typically physically segregated from untolled lanes.
TCP	Transmission Control Protocol
UBI	Usage-based Insurance
VIAPASS	VIAPASS is a GNSS-based distance charging system applied for trucks 3.5 metric tons (~7,700 lbs.) or more in Belgium. It replaced the Eurovignette system in Belgium beginning in April 2016.
VIN	Vehicle Identification Number
VMT	Vehicle Miles Travelled
3G	Third generation mobile communications standard that allows mobile phones, computers, and other portable electronic devices to access the Internet wirelessly.
3GPP	3rd Generation Partnership Project is a collaborative project aimed at developing globally acceptable specifications for third generation (3G) mobile systems.
4G LTE	LTE is a 4G cellular communication standard that supports HD video streaming, download speed as high as 299.6Mbps.
5G	5th generation mobile networks or 5th generation wireless systems, abbreviated 5G, are the next telecommunications standards beyond the current 4G standards.
WA RUC	Washington Road Usage Charge

1. Introduction

1.1 Purpose of Study

The purpose of this report is to highlight the key findings of the study on RUC Communication technologies commissioned by RUC West. This study was a survey of three categories of technology, each of which was covered in a separate whitepaper:

- technologies currently being used on RUC pilots,
- technologies used on other transportation and mobility operations that could be repurposed for RUC, and
- emerging and custom technologies.

This study examined the RUC recording and reporting technologies according to key technical and usability criteria that could support the selection of technologies in potential future RUC pilots or programs. The criteria included security, privacy, data quality, data continuity, and ease of use. The study did not attempt to determine the superiority of one technology over another, because RUC technology choices will depend on the specific RUC policy goals, budget constraints and internal skill sets of governing institutions, and public acceptance issues in the RUC program jurisdiction.

The benefits, drawbacks, opportunities and challenges associated with each RUC technology in the white papers are most meaningful when considered in the context of the desired outcomes of a given RUC program. Section 1.2 explains in more detail how technology should support policy goals. Section 1.3 describes common RUC policy goals and objectives for the main stakeholders, public acceptance, and how technology can be an enabler of RUC policies, once those policies are clearly defined.

In section 2, the final paper describes the key features of the technologies reviewed in the white papers. Section 2 includes a few high-level observations cover topics such as the relevance of these technologies for specific RUC policies, and the limitations that need to be considered for each technology. Detailed information on each technology, including the full analysis of the technology from the whitepapers, is included in the appendix

In section 3, the final paper provides a vision on the convergence of the different types of technologies examined. It discusses the consolidation of the information, location, and communications technologies that support RUC on light-duty vehicles and presents a notional timeline of technologies and an analysis of their maturity.

Section 4 includes high-level business case considerations and will cover high-level business implications of RUC programs. In general, technology vendors will require the incentive of profitability in order to support RUC. In particular, for the private sector to invest in research and design tools specifically for RUC, there should be a clear business case.

1.2 Technology supports policy goals

While technology is a fundamental enabler of RUC programs, technology should not be a primary driver of policy decisions. That is because today, technology can be developed and customized to suit the policy goals selected. In general, policy goals for a RUC program should be determined first, and then technologies can be selected that are most suitable and provide the most cost-effective support for these goals. Section 3 below covers potential policy goals and guidelines.

In addition to supporting a desired set of RUC policy goals, technology choices should address primary needs of three groups of stakeholders: governing institutions, technology providers, and end-users. Governing institutions want reliable technologies that clearly support policy goals, are not costly to deploy and administer, and easy to distribute and administer. Technology providers want to profit from their technology and operations. Finally, public end-users determine public acceptance. End-users should not be asked to invest an excessive amount of time to understand or use RUC technologies, especially in light of the fact that that no technology or time investment is currently required under the gas tax. Balancing the goals of the three group of stakeholders is key to finding the best technology fit to support a policy.

The fact that a technology answers policy and functional requirements and is cost-effective does not guarantee acceptance among all end-user profiles. Imposing a specific “black box” technology on private drivers on the basis that these technologies fill policy or functional requirements is not a politically viable approach. A technology that achieves high levels of accuracy and offers value-added services will not be appealing to some people due to their perception of its intrusive nature. Experience in the California and Oregon RUC pilots shows that individuals want to be able to choose the RUC reporting methods of their choice. End-users (drivers) have also shown willingness to make trade-offs between the ability to distinguish between miles reported and privacy, so end-users should be provided with options to make such trade-offs. To encourage policy support, technology options have to be broad enough to satisfy the needs of different end-user types. It may not be politically feasible to support a RUC program with only one type of technology. In general, RUC programs may need at least one location-based technology and one non-location-based technology to satisfy all groups of end users.

Technology can help reinforce RUC policy messages with the public. Through its vast reach and convenience technology can help members of the public better understand and accept novel methods of road funding. However, poorly implemented technologies can seriously harm a policy. A costly implementation or poorly designed technology that leads to negative user experience, for example, could undermine RUC policy efforts. Technologies that have limited accessibility or are very complex to implement or use will harm policy, because they will not be perceived as being cost-efficient, inclusive and fair. Policy should therefore be the starting point that guides technology choice, and technology should strive to consistently support policy goals.

1.3 RUC Policy goals and guidelines

Clearly defined policy guidelines can help governing institutions address key stakeholders' interests and establish technology requirements without being over-prescriptive. Rather than specifying exactly what the technology should be, policy goals generate criteria that have to be met in terms of security, accuracy, data integrity or interoperability should be specified. Defining technologies through such criteria helps attract different types of technology provider to the RUC environment, thus encouraging innovation. Public agencies tasked with implementing RUC may benefit from private sector expertise and recommendations when it comes to understanding emerging technology trends. The use of new technologies can reduce the risk for governments to invest in technology that could become obsolete prematurely and can also help governments improve their systems.

Below are some important policy guidelines, established on past RUC pilots, that were used to orient technology decisions:

Transparency: "A road usage charge system should provide transparency in how the transportation system is paid for"

The first step to win public acceptance is to make sure that end-users understand both what RUC is about and how they are charged under a RUC system. This is especially important when end-users are being asked to transition from a simple system, the gas tax, to a RUC system. To effectively support RUC policy, the data collection technology should be able to provide detailed RUC information – for example, number of miles collected, fuel consumption, the rate applied—and location, if the technology includes location.

Cost-effectiveness: "The administration of a road usage charge system should be cost-effective and cost-efficient."

Implementing a RUC system implies maintaining customer service, data collection and processing systems, back office systems, and enforcement systems. One of the major push backs against the RUC system is the cost of operation. While it may be possible to justify the one-time capital investments needed to develop and set-up a system, the technology and system implemented for RUC should not be unnecessarily costly to operate in the long run, although they may be more expensive to operate than the current gas tax system.

Privacy: "A road usage charge system should respect an individual's right to privacy."

The RUC technologies reviewed in this study, aside from some types of pay-at-the-pump, are account based. This means that personal information, vehicle information, payment information and drivers' trip data are recorded in the systems. All of this information must be maintained in a way that is private—not shared with other entities, except as a user chooses.

End-users who are reluctant to share their location information should be given the option to choose non-location based methods. For users who agree to use location-based methods, privacy policies should be strictly respected and enforced to maintain participants' trust in the system.

<u>Data security</u>: "A road usage charge system should meet relevant data security standards, and access to data should be restricted to authorized people."

The importance of data security in an account-based RUC system is heightened compared with the gas tax. Account-based RUC requires that participants provide at least some personal data in addition to payment data. While some end users may be willing to make compromises between data reporting and privacy, all end users have very high expectations when it comes to security. RUC technology needs to have robust security mechanisms that can guarantee protection of individual's private information. Security requirements need to be established against latest industry standards.

<u>Simplicity</u>: "A road usage charge system should be simple, convenient, transparent to the user, and compliance should not create an undue burden."

Experience on mobility projects reveal that complex policies rarely gain adoption. More savvy pilot participants may be willing to explore policy intricacies during the first few months of a pilot, but enthusiasm may die out after the novelty wears off. If technology needed to support a complex policy turns out to be time consuming or complex to use, end-users will stop making efforts to be compliant. The most effective policies are the ones that are intuitive, convey RUC policy messages simply, and do not need constant reminders for users to become compliant.

<u>User choice</u>: "Consumer choice should be considered wherever possible."

Acknowledging that end users have varying needs and different levels of technology savviness is important for the success of any RUC program. Some end-users may choose to trade convenience for perceived improvements to privacy. On the other hand, drivers who perceive a personal benefit to the value-added services that come with plug-in devices may be more inclined to sharing the data necessary to access the full functionality of those apps. Individuals who are not technology savvy cannot be asked to verify compatibility of apps, or maintain a compliant device. They should be given less technical options that allow them to reach compliance easily.

2. Summary and perspectives on the three categories of technologies studied

This section provides a high-level description of technologies with current or possible future applications to RUC. The technologies are divided into three categories: (1) RUC technologies currently in use, (2) mature technologies developed for other applications that could be re-purposed for RUC, and (3) emerging technologies that may have RUC applications. Detailed descriptions, including information gathered through vendor interviews, are provided in the appendix.

The various technologies described in this paper are generally comprised of three basic technology elements - radio, GNSS, and database/data mining. Even the emerging “technologies” are, for the most part, an application of some combination of these three basic technologies. As illustrated in Figure 1, the information, communication, and location technologies currently used for RUC reporting were typically developed decades before their application to RUC.

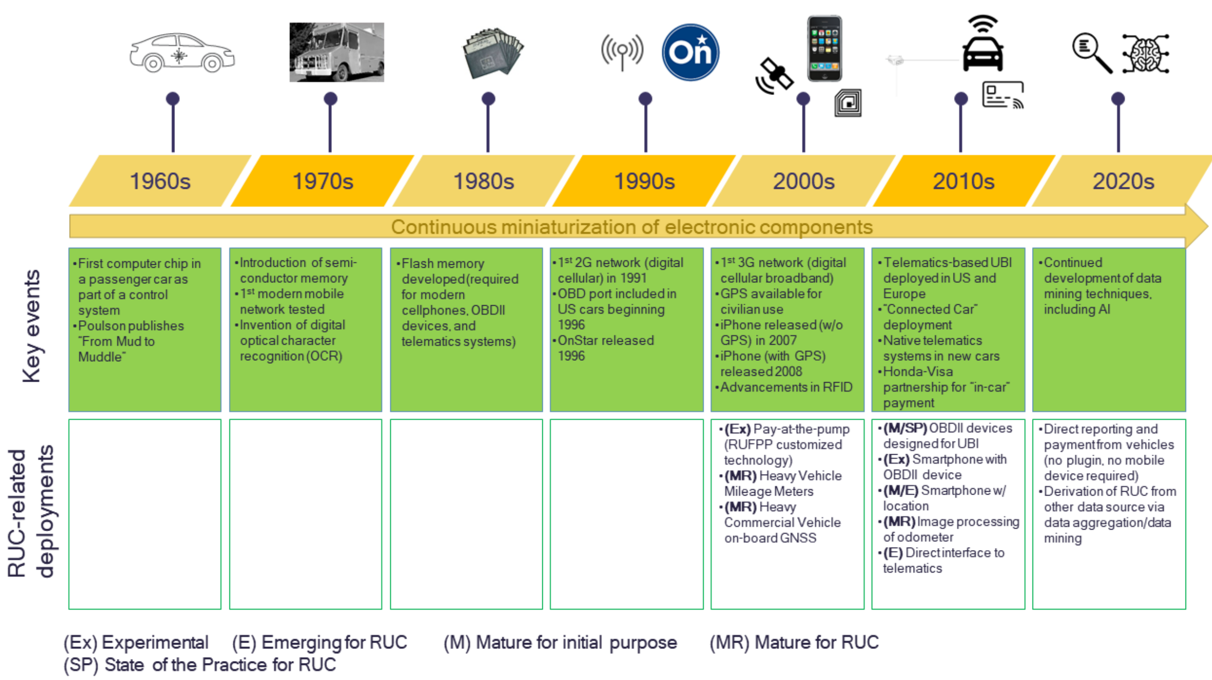

Figure 1. Development and Application of Technologies used for RUC[1]

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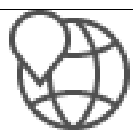
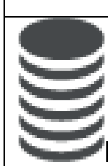
[1] Roy Poulson’s 1964 paper “From Mud to Muddle” is sometimes credited as the first discussion of RUC in an academic context. The van pictured above 1970s is the van that housed the first modern mobile digital network in a vehicle.

 Radio	Mobile telephones and the cellular chips embedded in OBDII dongles are low-power two-way radios. Cellular communication, whether it is mobile 3G, 4G, or 5G, are all digital radio applications. Phones and OBDII devices generate digital packets containing the data they need to transmit (voice or RUC data), and then transmit those packets to a stationary radio receiver (cell tower). Over the last three decades, incremental improvements to mobile communications have included development of cellular networks (as opposed to broadcast networks), reductions to the size of transmitter/receiver equipment (chips), and the switch from analog to digital transmission. The chipsets that support Bluetooth communication are also low-power (much lower power than mobile phone) radios that can both transmit and receive radio signals over a short distance.
 GNSS	In most of the technologies presented below that utilize location information, the ability to determine *where* miles are driven depends on a Global Navigation Satellite System (GNSS) application. In North America, the GNSS system available to commercial providers is called the Global Positioning System (GPS). At their core GNSS systems, including GPS, are also radio networks. However, unlike cellular communications which are two-way, GNSS receivers found in mobile phones, OBDII devices, and vehicle telematics are one-way devices - they only *receive* signals. They use the signals received to determine the location of the GNSS system. As with mobile radio communications, recent advances in GNSS technology have been largely incremental. The size of receivers, antennas, and the processors that determines location from the radio signals received has decreased significantly, allowing GNSS to be embedded in mobile phones, OBDII devices, and vehicles. Antenna sensitivity has also been improved upon.
 Database	Databases, and more specifically data mining techniques, form the third category of technology that is used to derive charging data for RUC. Of the three groups of basic technology elements considered here, the data mining has seen the most true innovation over the last several years. Advanced data mining techniques and Artificial Intelligence (AI) are making it possible to search and combine massive datasets, and synthesize them into usable RUC data. Virtually all of the technologies described in this paper use databases. Some of the data aggregators discussed in the appendix are taking advantage of advances in data mining, but AI and advanced data sorting algorithms may also support the use of native 5G data for some RUC applications. For the purposes of this report, we assume all account-based RUC implementations will contain a database on the back-end for account management and billing purposes. Here, primary technologies are assigned based on how core RUC data is determined, not how that data are processed for billing.

2.1 RUC Technologies Currently Being Used in the USA and Internationally

Name	Description	High-level Observations	Primary Policy Support

OBDII (with and without location)	• Devices that originated in the Usage Based Insurance (UBI) industry.
	• Devices that drivers can plug into the OBDII port of a vehicle to record certain aspects of driving behavior
	• Include devices with and without location-sensing technology (GPS)
		• Widely used in RUC pilots
		• Security issues being addressed
		• Ever-expanding range of value-added services
			• Accuracy
			• Cost effectiveness
			• Enhanced services
			• For location enabled:
			  ▪ Transparency (charge per jurisdiction)
			  ▪ Interoperability

OBDII coupled with Smartphone (switchable reporting device)	• Dedicated smartphone app coupled with OBD-II device via Bluetooth • Used in Oregon's second Road Usage Charge Pilot Program, provided by Raytheon • Could switch location recording on and off	• Devices were somewhat buggy • No longer supported by only provider (Raytheon) • Ability to switch location recording on and off was useful	• User Choice (between location accuracy or privacy)
Smartphone with Location	• Stand-alone smartphone app • Used proprietary algorithm to determine if the phone was in the driver's primary vehicle; supplemented with odometer images • Provided by Driveway in California Road Charge Pilot Project, with odometer image technology provided by Vehcon	• In California RCPP, some participants raised concerns about excessive data usage and cell-phone battery drainage • Other smartphone apps covered in repurposed and emerging technologies below • Requires active compliance by drivers (phone must be in car, charged, and turned on for every trip)	• Simplicity (convenience) • Cost effectiveness (no cost of distribution)

Name	Description	High-level Observations	Primary Policy Support
Image Processing via Smartphone or Mobile Phone without location	• Drivers periodically capture and submit odometer images with their own smartphones • System determines odometer reading and executes anti-Fraud measures • Provided by Vehcon in California Road Charge Pilot Project, and by Vehcon and IMS in Washington RUC Pilot	• Technology works well • Main difficulty is that it requires periodic activities by drivers. Drivers may forget to submit images, even when given multiple reminders, leading to data continuity issues	• User choice (semi-manual option) • Privacy (no trip information recorded) • Enforcement / antifraud
Software interface to native automaker telematics	• A third-party software provider creates an interface to native automaker telematics systems for the RUC Account Managers • Provided by Smartcar in California Road Charge Pilot Program • Direct use of native automaker telematics covered separately in Emerging Technologies section	• Allowed first use of telematics in a road charge pilot • Supports limited makes and models of vehicle, but list is expanding • Limited support of location-based charging	• Accuracy • Simplicity (no action required) • Transparency • Cost effectiveness
Heavy Vehicle Mileage Meters	• Dedicated mileage meter for collecting Heavy Vehicle RUC charges • Used in New Zealand and Oregon. Provided by EROAD in California Road Charge Pilot Program	• Provided secure, accurate mileage reporting for heavy vehicles • Only financially, technically feasible use is in heavy vehicles	• Security • Accuracy • Transparency • Compliance with regulatory framework (ELD)
Heavy Commercial Vehicle GNSS On-Board Units	• Similar to Heavy Vehicle Mileage Meters but can be self-installed by drivers, also require in-person enforcement • Used in Germany, Belgium, Hungary	• As with heavy vehicle mileage meters, work well, but only financially, technically feasible use is in heavy vehicles	• Accuracy • Enforcement • Transparency

2.2 Technologies that could be repurposed for RUC

Name	Description	High-level Observations	Primary Policy Support
DSRC and RFID On-board units (transponders) used in Electronic Toll Collection Systems	• Use onboard units (OBU) (also called transponders or toll tags) that communicate with roadside readers (transceivers) • Used extensively in electronic tolling	• Can only measure at locations with roadside receiver, thus, the necessity for widespread infrastructure make them cost-infeasible for distance-based RUC • Could be combined with other RUC technologies for enforcement, or used as a technology to measure out-of-state drivers	• Enforcement • Interoperability
Automatic License Plate Recognition (ALPR)	• Involves digital cameras that read vehicle license plate numbers through optical character recognition • Used extensively in electronic tolling	• Like DSRC/RFID above, can only measure at locations with roadside receiver, thus, the necessity for widespread infrastructure make them cost-infeasible for distance-based RUC • Could be combined with other RUC technologies for enforcement, or used as a technology to measure out-of-state drivers	• Enforcement • Interoperability
Smartphone as Transponder	• Small RFID sticker attached to the back of phones, turning phone into toll tag • Solution proposed by GeoToll	• Same drawbacks as DSRC/RFID for being a stand-alone solution • Could support combination of tolling and RUC, RUC payment, enforcement	• User choice • Simplicity • Enforcement

Name	Description	High-level Observations	Primary Policy Support
CAN Bus Clip Connector	• Device attaches to heavy vehicle CAN bus to capture mileage, fuel, other information • Used in Europe; provided by Masternaut and Technotron	• Only compatible with heavy vehicle CAN bus and requires some skill to install • No location information • Unlikely to be used in US—ELDs will be used instead	• N/A
Electronic Logging Devices (ELDs)	• Device that enables professional truck drivers and commercial vehicle fleets to track and report Hours of Service (HOS) compliance • Mandated on all US interstate heavy vehicles since December 18, 2017	• Most ELDs will provide sufficient accuracy and fraud resistance to be used for RUC recording and reporting, but lowest level (cheapest) ELDs may not • Not required for intra-state trucks	• Compliance with regulatory framework (ELD)

2.3 Emerging Technologies

Name	Description	High-level Observations	Primary Policy Support
Smartphone with Location	• Covers all smartphone with location options beyond those discussed in section 2.1 above. • All such apps have significant limitations, including their inability to independently distinguish between vehicles, verify that all miles traveled by a vehicle are captured, and distinguish between “driver” and “passenger” roles while in a vehicle. • One such app, proposed by GeoToll, pairs the phone to the vehicle via Bluetooth.	• Current and proposed smartphone-based RUC solutions require additional hardware (e.g., an OBDII dongle), a Bluetooth connection between the smartphone and car, or additional manual reporting (e.g., submission of odometer readings) by motorists, but even these requirements do not address all the shortcomings of current smartphone RUC apps.	• Simplicity (convenience) • Cost effectiveness (no cost of distribution)
Pay-at-the-Pump	• Range of technologies by which drivers can transmit RUC data and pay for RUC while they are buying fuel (gas, diesel, or electricity). • Could be transactions-based, requiring no account, and require no additional activities beyond what drivers do already • Solutions proposed by Verdeva, JumpDrive, and Gilbarco-Veeder Root / Honda consortium	• Would require gas station/charging station outfitting / integration into station payment systems • Unlikely to be ultimate solution for electric vehicles since they do not require a “station” for charging • Requires significant up-front investment to cover all gas stations in a given state	• User choice • Simplicity • Privacy

Name	Description	High-level Observations	Primary Policy Support
Digital License Plates	• Include a LCD display that shows the vehicle license number while also containing communications, GPS chipsets, and on-board memory • Provided by Reviver and Compliance Innovations; interest in deployment by several states	• Will not be cheap (several hundred dollars each); business case is still not clear • Self-installation possible but nontrivial—many people will need a mechanic to do it • Use batteries that will eventually need to be replaced	• User choice • Enhanced services
Native Automaker Telematics	• Direct support of RUC by automaker telematics (unlike the software interface covered in 2.1) • Automaker telematics systems rapidly emerging: by 2020, 80% of new vehicles may have them • Generally agreed to be the easiest, most convenient means of RUC data recording and reporting because they have great data accuracy and continuity and require no additional hardware.	• Limited ability to support older vehicles • Need to convince automakers of the need to support RUC – need to see a business case • Need to develop reliable transfer of ownership indicators	• Accuracy • Simplicity • Cost effectiveness (no cost of distribution) • Transparency (detailed charges per jurisdiction)

Name	**Description**	**High-level Observations**	**Primary Policy Support**
U.S. DOT Connected Vehicle Program	• A national effort to enable and deploy multiple connected vehicle applications, including both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. • No longer focused exclusively on 5.9 GHz DSRC as the base—open to any technology that can support V2V and V2I communications • No longer an emphasis on a large-scale roadside infrastructure rollout • NHTSA mandate to include technology in all new vehicles not issued in 2017. Still moving forward but not clear when it will happen	• Generally has automaker support, but likely to become just another feature of native automaker telematics systems (see above) • Two possible approaches to enabling payments: 1. Developing native applications themselves 2. Creating a secure “sandbox” for third-party applications (app store for the vehicle)	• Accuracy • Simplicity • Cost effectiveness (no cost of distribution) • Transparency (detailed charges per jurisdiction)
5G Mobile Communications	• Next generation of cellular communications, using 30-300 GHz band • Very high-speed communications • Could drive down communications costs • Could generate location information without GPS in some cases • Deployment expected to begin in 2020	• Deployment will be gradual, starting in urban areas, and could take 10 years to cover the whole country • May effectively be a complement to native automaker telematics	• Cost effectiveness (low communications costs in the long run)

Name	Description	High-level Observations	Primary Policy Support
Fleet Vehicle Technology	• Telematics services for light vehicle fleets • Many providers, such as Verizon Networkfleet and General Motors Fleet • Could generate RUC data for the vehicle fleet	• Not suitable for private vehicles or heavy vehicles—only suitable for light vehicle fleets • Could be important solution for fleets, especially those that already use an OBD-II dongle	• Security • Transparency (detailed charges per jurisdiction) • Enhanced services for fleets
Next-Generation Electronic Road Pricing (ERP) System in Singapore	• GPS-based congestion pricing system planned for Singapore in 2020. • Will assess RUC by distance, location, time, and vehicle type and provide real-time traffic information	• Requires an OBU in every vehicle • Requires GNSS • Very important to follow the rollout, but unlikely to gain widespread support in the US in the near term.	• Accuracy • Enforcement • Transparency (detailed charges per jurisdiction)
Telematics Data Aggregators	• Companies that collect and compile data from telematics-equipped vehicles that have opted in to the telematics data aggregator's services • They provide additional data analysis for customers and sell the aggregated data to businesses • Could support RUC payment for a wide range of existing telematics equipped vehicles	• Requires end-user permission • Will require business case for aggregators to support RUC • May eventually merge into native automaker telematics; could provide a means for automakers to support RUC	• Privacy • Security • Simplicity • Cost effectiveness
Blockchain	• Distributed digital ledger, allowing secure, anonymous third-party handling of data	• Cannot be used as a RUC recording and reporting technology	• Security

3. Convergence of technologies

When we talk about “automated reporting” or “automated RUC”, what we mean is a RUC reporting system that requires a minimum of human (driver) interaction or intervention. A motorist may have to install a device, download an app, or install an RFID tag in their vehicle, but after that, distance travelled, and if desired and appropriate, location should be reported “automatically” by whichever device, app, or system is selected. In most current conceptions of automated RUC reporting, this requires two mandatory and one optional components: (1) the vehicle, (2) communications, and (3-optional) GNSS (Figure 2).

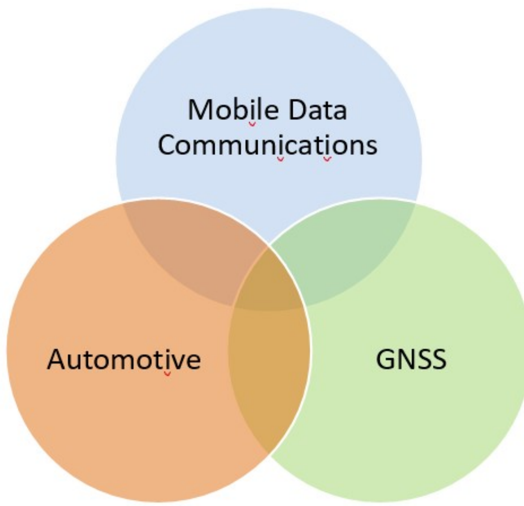


Figure 2. Automated RUC components

In the past, third-party tools such as smartphones and OBDII plug-in devices have provided the communications and GNSS capabilities necessary for automated reporting because cars were relatively simple mechanical devices and did not incorporate communications or GNSS technologies. While computer chips of various types have been present in some light passenger vehicles since the late 1960s, and in virtually all passenger vehicles since the 1980s, they were primarily focused on vehicle component/system controls, such as fuel injection and ignition control systems. Over time, additional automotive systems became “electronic” and manufacturers began to include a centralized control unit to manage the activities of various systems, including air conditioning, fuel injection, and odometer. In the 1980s and 1990s, California’s adoption of the original OBD standard (and later OBDII) forced auto manufacturers to provide a uniform port for outputting sensor data to determine emissions-relevant information from the various electronic systems. The original intent of this port was to allow an external computer to plug temporarily into the vehicle to access internal sensor data.

So, automatic RUC reporting for many vehicles has required at least two distinct devices: (1) the car, and (2) an after-market device capable of transmitting driving data and deriving distance (and possibly location). Commercial OBDII plug-ins used for UBI and RUC are, in effect, small, single-purpose external computers that plug permanently (or nearly permanently) into the diagnostic port, with the ability to read data from vehicle systems, package that data into a useful format, transmit it to a remote location, and possibly determine precise location. The same is true of smartphones – they are very small computers with the additional capability of voice telephony. The major drawback of mobile phones, when compared to OBDII units is that they do not maintain a physical connection to the vehicle, and thus are not guaranteed to have power or even be in a vehicle when it is being operated.

Over the last two decades, automakers have begun to incorporate both mobile communications and location technologies into light-duty passenger vehicles. Initially, both were incorporated into systems originally intended primarily for safety, such as On-Star. In early implementations, neither the communications nor the location capabilities were generally available to drivers, but were "hard-wired" directly to customer service centers. For instance, early vehicles equipped with On-Star did not have a map display or offer mobile-phone pairing, nor was the mobile chip inside the On-Star unit allow motorists to contact anyone except On-Star. The GNSS functions were designed exclusively to allow On-Star to locate a vehicle, and the communications were solely for use in emergencies.

Due largely to consumer demand, but also to falling mobile communications costs, automakers did eventually begin to offer in-vehicle navigation systems, and more recently, embedded 4G chipsets. Although such systems may contain the originally implemented safety functionality, now nearly all in-vehicle communications are marketed primarily as "infotainment" packages and are designed to allow passengers to stream music or video, or to provide Wi-Fi hotspots in the car. As such, they are largely separated from vehicle control systems, they often may not have access to vehicle control systems data . The US Connected Vehicle program has spurred some automaker development into using 4G chips to transmit some types of vehicle data to either nearby vehicles or static infrastructure, but this is not widely deployed in infotainment systems. Figure 2 presents an outline of technologies incorporated into current RUC systems.

Beyond pure safety and infotainment systems, there is a third, more fully featured category of embedded communications technologies that are more directly applicable to RUC, called in-vehicle telematics. Largely coincident with the entry of plug-in electric vehicles to the US market, automakers began offering such telematics packages. On the driver-facing side, these packages consist of touch-screen controls for audio, mobile-phone pairing, navigation, infotainment, and vehicle health information. However, for automakers, these systems can provide a treasure-trove of operational data. Many telematics systems, particularly those in PHEVs, routinely and continuously transmit vehicle location and performance data (battery health, batter usage, etc.) back to the manufacturer. These data are used to improve battery and motor design, but contain key information – vehicle ID, distance driven, time, and location – that could be used for RUC if they were made available by automakers. Because such systems would have simple user interfaces that are fully integrated into the vehicle, native automaker telematics systems represent the easiest, most convenient means of RUC data recording and reporting. The data could be transmitted into a RUC system as a data source for account managers, or could be transmitted to Pay-at-the-Pump technologies to support a transactions-based system (see section on Pay-at-the-Pump for details). It is worth noting, however, that automakers are extremely focused on the security of this data, and historically have been reluctant to share it with government or other private sector entities. The incentive to share the data they are collecting may come from consumer demand and/or financial incentives made by states.

Figure 3 illustrates the evolution of RUC reporting from analog to completely automated, supported by the development of technologies like telematics. The potential use and constraints of native automaker telematics is discussed in the third whitepaper appendix.

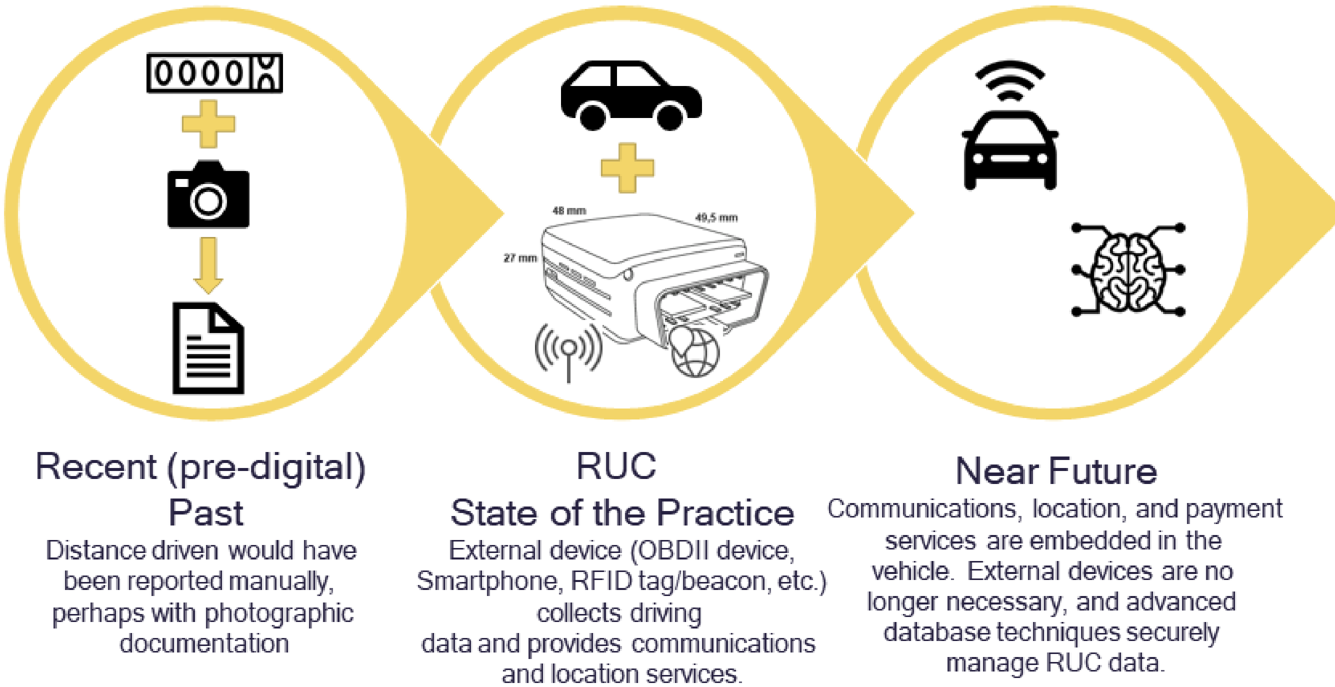


Figure 3. Implementation of Technologies for RUC

4. RUC technology business considerations

States considering a RUC program should be aware of the business implications of engaging with the technology vendors. This section provides a high-level overview of RUC technology business considerations.

Currently, the only market for light vehicle RUC technology in the world exists in Oregon, and the Oregon market is limited in scale due to the opt-in nature of program. As other states implement RUC programs and the market expands, the business relationships with RUC technology providers will evolve. Fundamentally, there needs to be a business case for RUC technology providers—they need to be able to make a profit in the short to medium term in any permanent RUC program, unlike in pilots, in which technology providers may be willing to break even, or in some cases, to work for a loss.

A law that permanently mandates RUC for a sufficient number of vehicles will create a market for RUC technology. However, when introducing a RUC program, vendors will be more eager to support the RUC market when the business case—the path to profitability—is clear. This means that states mandating RUC should provide incentives to technology vendors, which may take the form of per-item or per-time fees, or a percentage of RUC revenue.

Setting the incentives correctly may take significant effort, because it is not in the public interest that vendors make exorbitant profits, but the RUC program will fail if no quality vendors are willing to support it. Moreover, the incentives will change as the market evolves. In particular when the RUC market it small, vendors will need greater incentives, but as more vehicles become subject to RUC, the incentives may be lowered (both for fees and revenue percentages), as the vendors experience economies of scales. When the market is large and mature enough (e.g., with tens of millions of vehicles subject to RUC), it is conceivable that the need for incentives may disappear entirely, because the RUC technology vendors may make their profits from secondary revenue streams (e.g., insurance). But it is highly uncertain whether the need will disappear completely.

Vendor technology costs are comprised of capital and operating costs (processing and communications) costs. Capital costs, typically hardware costs, are primarily relevant for a OBDII devices, which cost $50 when purchased at scale. Operating costs include costs to develop and maintain software to process RUC data, and costs for data communications. Data communications costs continue to decline on a per bit basis, and with some technologies, may be able to be transferred to the consumer/motorist (e.g., in the case of the motorist using his/her own smartphone for communications), but some operating costs will always remain for every technology.

The business case for vendors, and the exact nature of incentives, will vary by technology. For the more promising technologies, we provide high-level business case considerations for promising technologies as follows:

OBDII devices—The primary consideration with OBDII devices is to couple them with Usage-based or Pay-as-you-go insurance and the range of value-added services that are offered on these devices. Some insurance companies currently pay for these devices to be on their customer's vehicles already, thus covering capital and operating costs. It is possible that even such companies may require a small subsidy to support RUC. It is also possible that an OBD-II system provider, such as Azuga, DriveSync/IMS, or emovis, could support this system, but require a fee from the state or from drivers unless and until the driver chose insurance from a company that they support.

Image processing via smartphone—While image processing software is relatively inexpensive to operate, it is not free. Thus, using such software may require some investment by the state. However, support for this implementation of RUC could be combined with app-only insurance such as that offered by Mile-Auto.

Smartphone apps—RUC reporting via a smartphone app has been extraordinarily attractive to policymakers due to the deep penetration of smartphones across the country. Since most drivers already own a smartphone and have a communications plan, RUC technology distribution and communications costs would be negligible. However, tests of smartphone-based RUC reporting have indicated a fundamental shortcoming: smartphones are only able to detect and report mileage if they are in the vehicle when it is in motion and have sufficient battery power. Furthermore, apps that rely on smartphone electronics are not able to reliably distinguish between vehicles or determine whether they are in a "driver" or "passenger" role. Some of these issues may be resolvable with additional app development (for instance, smartphones/apps can determine the are in the correct car via Bluetooth IDs (assuming the vehicle has Bluetooth), but that development carries costs and may not be a perfect solution. Another approach may be for smartphones to interact directly with telematics systems (assuming the car has a telematics system) to aggregate and report RUC data, bypassing some of the current limitations of both smartphone apps and telematics systems. This approach is likely to carry more significant development costs and is unlikely to be developed without both broad policy support and a viable market.

Electronic Logging Devices (ELD): Heavy vehicle mileage meters, such as those offered by EROAD and Coretex offer ELD services, are already compliant with RUC systems, and operate at no cost to the state or countries they support. Many other ELD providers may provide sufficient accuracy and fraud-resistance, but as indicated above, the entry-level ELDs may not. However, it is likely that a heavy vehicle RUC mandate in any give n state would encourage ELD providers to become compliant with RUC requirements. Thus, it is likely that no incentives would be needed to get ELD providers to support RUC for heavy vehicles—they would just add it to the services they are already selling to interstate heavy vehicles.

Automatic License Plate Readers (ALPR)– As described above, ALPR is not useful as a primary source of RUC information for most vehicles, but could be used for enforcement and/or a supplementary system to charge out-of-state vehicles. To support such deployments, a portion of fines collected could be dedicated to paying the ALPR suppliers, and/or a portion of revenue from out-of-state vehicles could be dedicated to supporting ALPR systems at state borders.

Native Automaker telematics / USDOT Connected Vehicle Program / 5G—Native Automaker Telematics—supported by connected vehicle technologies and emerging 5G communications—is likely to eventually support RUC after RUC is mandated. Automakers will see the need to support their drivers paying RUC in the easiest, most convenient manner. However, it may take some time for each automaker to develop and deploy such services, and providing a source of revenue to them to offset their costs could cause them to support RUC communications more quickly. Also, there are ongoing costs associated with providing data in a secure way, and maintaining RUC services. Thus, providing a small amount of revenue per active vehicle would be helpful to get all automakers' telematics systems onboard. Partnering directly with automakers on one or more RUC pilots would provide insight to all parties about the challenges and possible business opportunities of supporting RUC via telematics data.

Fleet vehicle technology—Vehicle fleet technology providers could easily provide data to support RUC, and like automakers with their native telematics systems, will want to provide this service to their customers. They may be willing to add associated fees to their customers' invoices, so in case of a RUC mandate, such providers may be willing to support RUC without subsidy.

Digital License Plates – The current business model for Digital License Plates (DLP) focuses on (1) regulatory compliance efforts such as providing visual cues to law enforcement of expired vehicle registration or insurance, (2) fleet management services, and (3) lease of advertising space. Additional smart city applications could open additional revenue streams (for instance, DLP could eliminate the need for parking meters and parking enforcement officers). The key assumption is that the *value to government of increased compliance offsets the higher cost of DLP* when compared to traditional metal plates, so governments will be willing to purchase the more expensive plates. As with the other technologies discussed here, there is no current "RUC" business case for DLP but some solutions, such as Reviver's, will very likely be RUC-ready with only minor database changes. However, minor database integrations with government agencies have historically been quite complex, and appropriate development costs should be accounted for.

Pay-at-the-Pump – Pay-at-the-Pump systems will require a state payment to the system provider. Gas stations and electric charging station owners will not want to pay. The system providers would likely be interested in an up-front payment for capital costs, and a relatively small transactional payment for each vehicle supported.

5. Conclusion

As states (or the Federal government) explore RUC program design, it will be important for them to remember that *all* of the technologies described here are designed, developed, and marketed for purposes other than RUC (aside from some technologies used solely for heavy vehicles). Indeed, aside from the heavy vehicle technology, dedicated “RUC technology” does not exist. That does not mean that existing technologies cannot or should not be used for RUC, but that they were fundamentally developed for other purposes, and it is important to recognize that commercially-available tools have been optimized for other applications and other markets. For example, an OBDII device designed for the UBI market very likely performs exceptionally well for UBI applications but may require some adjustments to be more than “adequate” for RUC. Likewise, smartphone apps designed to log trips for business deductions or tax purposes may excel in those applications, but additional development may be required for them to adequately support RUC. Existing technologies should not be rejected because they are not perfect. Indeed, as stated above, there is not really a RUC market in the US, so nobody is investing heavily to develop the perfect RUC technology. Rather, pilot and research deployments should identify their specific shortcomings relative to policy requirements and user acceptance so that (1) limitations are clearly understood as RUC programs are established and (2) the shortcomings and limitations can be addressed as RUC markets develop.

The improvement cycle that supports existing technologies being optimized to support RUC policies requires an effective partnership between policymakers and technology providers. Such a partnership would maintain the momentum in research and development while RUC policies continue to be tested. Pilot programs offer an excellent opportunity for governing institutions to keep the private sector involved. As discussed in section 4, private firms need to see a significant incentive to invest in RUC technology and will not engage in RUC operations without a business case. RUC pilots, given their scale and experimental nature, present lower investment risks than full-fledged RUC operations deployed across a state. Besides allowing policy tests, pilot programs provide a complete simulated RUC environment for governing institutions and technology vendors to test technical capabilities of technologies and public acceptance of those technologies. Pilots allow technology vendors to integrate their technologies with customer service, account management, and RUC administration systems, which provides the vendors valuable feedback on system implementation costs, operational costs, and usability issues. They are better informed on cost structures and end-user acceptance after participating in a pilot, and may be able to make better decisions on how to price their services and optimize their products for RUC. Moreover, participation in a given RUC pilot or program may make it easier for vendors to be qualified for future RUC pilots. RUC-focused states should capitalize on current technology providers’ efforts in pilots by continuing to provide incentives for them to engage in RUC pilots. In addition to optimizing existing technologies, vendors should be encouraged to take risks and introduce new technologies in the RUC ecosystem through partnerships with other innovative firms.

When optimizing technologies for RUC applications, technology vendors should consider end-users who will determine the extent to which a policy is adopted. Because the technologies have mostly been imported from other applications, both vendors and policymakers should ensure that the policy message is consistently presented by their technologies. End users should have more than one technology option, so that they do not feel constrained to use a technology that does not respect their privacy concerns, accuracy expectations, or adds complexity to their life. The challenge in designing a RUC program is to determine exactly which technology options will be the most or least welcome by different categories of users for their preferred policy goals, and consequently which technologies should be offered for a given RUC program. The data gathered on pilot projects is rich, but not sufficient yet to allow predictions on the best technology fit.

Compared to other transportation and mobility revenue collection operations around the world, there is little data on light vehicle RUC operations, and continued pilots are needed to correct this situation. Previous pilots indicate that the minimum requirement for a successful RUC implementation is an alignment of policy goals and technology, and communications strategy and plan that is customized for the public's level of acceptance. However, RUC remains a relatively unknown concept with the general public, and end-user reaction to policy and technology in many states is still uncertain. Only further experimentation will allow technologies and associated communications efforts to gain user acceptance and hence successful RUC deployment. Each pilot should be an opportunity to further experiment different mileage reporting technologies and can improve the quality of the data available on light vehicle RUC and end-user reactions.

Technology innovations outside of the primary technology for mileage recording and reporting will also impact the development of RUC technologies in the coming years, most notably, 5G communications and Blockchain. 5G communications will start implementation by 2020 and are certain to become dominant within a decade. 5G communications will further reduce data communications costs, enable an Internet of Things (IoT) that in turn will encourage greater use of native automaker telematics, and possibly allow location determination without the use of GPS technology. Blockchain technologies will enable distributed, anonymous, secure recording of RUC data from multiple sources. The system for data aggregation and distribution proposed by ClearRoad, though still in early development, could allow multiple states to share a single RUC data collection and accounting system, thus reducing the cost of RUC operations.

Appendix A
White Paper on Existing Technologies

Please refer to pdf on White Paper on Technologies Currently being Used (v1.1)

Appendix B
White Paper on Technologies that can be Repurposed

Please refer to pdf on White Paper on Technologies that can be Repurposed (v1.2)

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Appendix C
White Paper on Emerging and Custom Technologies

Please refer to pdf on White Paper on Emerging and Custom Technologies (v1.1)