Tolling Lessons Learned for Road Usage Charge

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A Research Report from the Pacific Southwest Region University Transportation Center

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16. Abstract
In 2021, the federal gasoline tax raised about $32.8 billion which accounted for about 70% of the Federal Highway Trust Fund's expenditures, with a shortfall of $14 billion (FHWA, 2021). In response, many states have launched pilot or full-scale programs of road-usage charge (RUC) as an alternative transportation funding source. One of the fundamental challenges of RUC is the high cost of implementation compared to a traditional motor fuel tax (Caltrans, 2017). To address this, states look to leverage existing vehicle-level pricing programs, such as road tolling to learn possible synergies between RUC and tolling. In this paper, the authors conducted semi-structured interviews with experts from tolling programs across the U.S. to identify areas of overlap between tolling and RUC. Consequently, they built upon the interview findings with a multi-criteria decision analysis (MCDA) to evaluate how ready the RUC pilot programs are for implementation. The results demonstrated that there are numerous lessons that the RUC pilots can learn from the tolling industry and develop an integrated system—tolling hub operations, methods to maintain data privacy, technology, etc. RUC programs can benefit from integration with tolling from the increased scale of operations which would largely reduce administrative costs. Lastly, ensuring equity in RUC rate design to alleviate any potential financial burdens on low-income populations and ensuring that unbanked and underbanked populations have access to the system is important.

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Pacific Southwest Region UTC
University Transportation Center

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The Pacific Southwest Region UTC conducts an integrated, multidisciplinary program of research, education and technology transfer aimed at *improving the mobility of people and goods throughout the region.* Our program is organized around four themes: 1) technology to address transportation problems and improve mobility; 2) improving mobility for vulnerable populations; 3) Improving resilience and protecting the environment; and 4) managing mobility in high growth areas.

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Disclosure

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Abstract

In 2021, the federal gasoline tax raised about $32.8 billion which accounted for about 70% of the Federal Highway Trust Fund's expenditures, with a shortfall of $14 billion (FHWA, 2021). In response, many states have launched pilot or full-scale programs of road-usage charge (RUC) as an alternative transportation funding source. One of the fundamental challenges of RUC is the high cost of implementation compared to a traditional motor fuel tax (Caltrans, 2017). To address this, states look to leverage existing vehicle-level pricing programs, such as road tolling to learn possible synergies between RUC and tolling. For this project, we conducted semi-structured interviews with experts from tolling programs across the U.S. to identify areas of overlap between tolling and RUC. Consequently, we built upon the interview findings with a multi-criteria decision analysis (MCDA) framework to evaluate how ready the RUC pilot programs in US are for implementation and integration with current tolling practices. Our results demonstrated that there are numerous lessons that the RUC pilots can learn from the tolling industry and develop an integrated system—tolling hub operations, methods to maintain data privacy, technology, etc. RUC programs can benefit from integration with tolling from the increased scale of operations which would largely reduce administrative costs. Lastly, ensuring equity in RUC rate design to alleviate any potential financial burdens on low-income populations and ensuring that unbanked and underbanked populations have access to the system is important.

Tolling Lessons Learned for Road Usage Charge

Executive Summary

Transportation funding in the United States has historically been supported by motor fuel taxes. In 2021, the federal motor fuel tax raised about $32.8 billion in revenue which accounted for about 70% of the Federal Highway Trust Fund's expenditures on infrastructures (FHWA 2022). With the increasing uptakes of alternative fuels vehicles, improved vehicles fuel efficiencies, and inflation, the revenues generated by the fuel taxes are dwindling down, creating shortfalls in the infrastructure funding (Jenn and Fleming, 2020). This is not only a concern at the federal level, as many states have explored ways to address the widening gap between transportation funding availability and needs. One of the alternative means of transportation funding that states have been considering is a road usage charge (RUC) program or a mile-based user fee (MBUF). RUC or MBUF can address the concern of decreasing revenues from fuel taxes because it is based on the "user pays" principle and it directly prices drivers for their usage of the roads. Additionally, as economists have long suggested, when designed appropriately, RUC or MBUF can also help address some of the negative externalities of the transportation sector like congestion. One of the challenges of adopting RUC, in replacement of the fuel taxes, is the large administrative costs associated with its implementation in addition to the technology, operational, and equity considerations. In this study, the objective is to understand how existing vehicle-level pricing programs, such as tolling can be leveraged in terms of knowledge of their administrative, operational, and technology challenges for RUC implementation and to learn of possible synergies between the programs. There are also equity concerns related to road pricing that will need to be accounted for political feasibility and public acceptance of RUC programs. Existing tolling systems and pilot RUC programs can also inform policy to design RUC that addresses these issues. From interviewing 9 tolling industry experts and reviewing state-level RUC reports, our research team gained insights on a wide range of topics concerning vehicle-level pricing programs and synthesized areas of potential integration between RUC and tolling. Finally, the report also touches on the equity implications of road pricing or RUC programs.

The insights obtained from our analysis provides invaluable lessons-learned in terms of the functioning of the tolling systems. While as an industry, there are some common practices and standards across tolling systems, different tolling agencies have tailored their technology and operation to meet the needs of their users. This is a major takeaway for RUC in terms of designing a program that has clear objectives of revenue generation for funding infrastructures, while allowing enough flexibility to handle regional differences. Another key takeaway is managing revenue leakage in the transition from a "pay now" to a "pay later" model when moving from motor fuel tax to RUC. Some potential safeguards of revenue leakage include partnering with the State's Department of Motor Vehicles (DMV) to streamline the process of data request and account matching, so the accuracy of transactions matching to accounts

increases. Another area of exploration is leveraging in-vehicle telematics to directly communicate with existing tolling technology in terms of mileage tracking. Technology implementation and handling revenue leakage are areas of expertise that the tolling industry has, which can be greatly leveraged to widely implement a RUC program. In terms of collaboration between the tolling industry and RUC, there is potential consolidation of back-office account management. Instead of creating a different customer service center that assists users with payments and processes transactions for billing, RUC implementation should consider leveraging the existing staffing and system infrastructures of the tolling industry. Lastly, an area that is highly relevant in rate design and administration of RUC is ensuring equity in terms of alleviating financial burdens on low-income populations and ensuring that unbanked and underbanked populations have the means to pay for their RUC. Timely research on equity in rate-design is invaluable and essential in a successful RUC implementation.

Introduction

In 2017, the state of California passed the Road Repair and Accountability Act (Senate Bill 1) that increased the tax rate on gasoline and diesel. The bill also introduced an annual registration fee on zero-emission vehicles to compensate for the fact that these vehicles do not contribute to road infrastructure funding via traditional fuel taxes. While many other states have also begun to enforce registration fees on electric vehicles (EVs), this form of revenue is often viewed as a stopgap measure as it is not directly linked to the amount of driving by the vehicle being taxed (since it is a flat-fee for every EV). In addition, an annual fee of $100 generates less revenue than the average amount raised from fuel taxes, which is about $310, assuming an average fuel efficiency of 25 MPG and an annual mileage of 14,400 miles driven in California (FHWA 2022).

Road pricing in the form of road user charge (RUC) or mileage-based fee, cordon pricing, or high-occupancy toll (HOT) roads can help generate the tax revenue required to meet the gap created by the transition to fuel-efficient and alternative fuel vehicles and the resulting lower gasoline consumption. As a result, in the US, a large number of states have begun piloting and, in some cases, even implementing road-user charge (RUC) programs, congestion tolling systems, and even cordon pricing. Considering specifically RUC programs here, rather than being directly linked to fuel consumption, RUC instead enact a fee based on the distance driven by an individual vehicle. Many states have launched pilot programs to investigate implementation issues related to RUC programs–including California, Washington, Hawaii, and the Eastern Transportation Coalition (TETC) with Oregon, Utah, and most recently Virginia launching full-fledged RUC programs where drivers can voluntarily opt-in to pay a RUC instead of gasoline tax. In 2022 alone, Hawaii, Massachusetts, Minnesota, Tennessee, Utah, Vermont, Virginia, and Washington have all considered bills to set up or expand existing programs for RUCs. Additionally, the federal Inflation Investment and Jobs Act (IIJA), passed at the end of 2021, directed the US Department of Transportation (DOT) to begin establishing a national per-mile road usage fee pilot. There is clearly substantial momentum at both the state and federal level to replace the gasoline tax with a RUC system, especially as the adoption of electric vehicles continues to grow.

One of the fundamental challenges of a RUC program is the relatively high-cost of implementation compared to a traditional gasoline fuel tax - higher administrative and enforcement costs (Caltrans 2017). The administration of the fuel tax benefits from the fact that fees are collected from a small number of bulk storage terminals (slightly more than a thousand across the entire US) while a RUC program would need to be assessed at a much broader scale with collection points at the individual vehicle level (numbering in the hundreds of millions across the entire country). While the administration of motor fuel taxes benefit from a smaller number of collection points, most of the other transportation-related programs, such as the collection of vehicle registration fees and tolls are more in-line with the collection of RUC

payments. Therefore, the percentage of administrative costs of RUC is more on par with those from the tolling programs and from vehicle registrations. One strategy to address issues related to administrative costs and other implementation challenges of RUC programs is to leverage existing vehicle-level pricing programs like road tolling systems to gain knowledge from their implementation challenges and learn of possible synergies between the programs. There are also equity concerns related to road pricing that will need to be accounted for political feasibility and public acceptance for RUC programs. Existing tolling systems and pilot RUC programs can also inform policy to design RUC that addresses this issue.

In this study, we look specifically at road-tolling programs, the lessons learned from the implementation of these systems, and opportunities that may exist within these programs to assist in the development of a RUC program. We reviewed the literature and our research team conducted 9 expert elicitation interviews with a variety of stakeholders related to tolling programs across the country. These experts represent a body of knowledge that spans many relevant topics in the tolling industry including development/deployment, technology, pricing and payment, policy, and (but not limited to) administration. Following the interviews, we analyzed the transcripts to identify key themes which are relevant to both tolling and RUC programs. We presented these findings and built upon them by conducting a multi-criteria decision analysis (MCDA) to evaluate how well the state-level RUC pilot projects conducted to date can integrate with tolling systems as well as learn from the latter. By synthesizing the insights gained from the expert interviews and the MCDA, we aim to provide guidance for successful and large-scale implementations of RUC. Finally, we include the analysis from an existing project focusing on the equity concerns associated with RUC programs to inform the equity concerns associated with RUC implementation.

History of Road Tolling and RUC Programs[1]

Economists have long advocated for pricing the use of roadways as it is an efficient way of allocating scarce roadway capacity and tackling the negative externalities, including congestion, air and noise pollution, and wear-and-tear (Vickrey, 1965). Some examples of road pricing include distance-based tolling, cordon tolling, congestion pricing, and mileage-based user fee or RUC. However, until very recently, road pricing has rarely been implemented and is strongly opposed by the public and elected officials due to its nature of charging drivers more fees. Because of its lack of popularity, point- and link-based tolling, unconnected to the time or extent of use has so far been the only forms of road pricing implemented in the U.S. Historically, the Federal Highway Act of 1921 provided financial assistance to states for building roads and bridges to improve nationwide connectivity in order to accommodate the rise of automobile usage. Tolls were collected on many of these roads, bridges, and tunnels to help pay for their construction and maintenance. The Federal-Aid Highway Act, passed in 1956, halted the need to collect tolls on these public transportation infrastructures, since it legislated the Interstate highway system to be funded by tax revenues, which continued for a few decades. However, by 1980, some of these originally constructed highways under the Federal Aid Highway Act began to wear out. The need for continued maintenance in combination with a shortage of government funds to support the infrastructure re-prompted the need for tolling. Since then, tolling and motor fuel taxes have remained the primary sources of funding for the maintenance and repair of the Interstate and general highway infrastructures in the U.S.

[1] The history of road tolling in the US has been summarized from the DOT report "Toll Roads in the United States: History and Current Policy"

Learnings from the Literature on Road Tolling and Road Pricing

While road pricing in the form of tolls is a source for generating transportation infrastructure funding in the U.S., when linked with time- and usage-based road pricing can address negative externalities of the transportation sector like congestion and pollution. Road pricing schemes are not new and there are numerous examples and practices both nationally and internationally. Road pricing has been implemented in other countries across the globe with the objective of addressing these externalities. The first application was in the form of congestion pricing adopted by Singapore in 1975 (Santos, 2005). Today, cordon tolling and congestion pricing are present in many cities worldwide, including London, Milan, Oslo, and Stockholm (Beevers and Carslaw, 2005), (Börjesson and Kristoffersson, 2018), (Lehe, 2019). Some of the major motivations behind these road pricing schemes included reduction of greenhouse gases (GHG) and local air pollutants and congestion mitigation (Beevers and Carslaw, 2005), (Deng, 2017).

To evaluate the impacts of road pricing on addressing negative externalities in the transportation system, researchers have conducted both quantitative and qualitative analysis. Some examples of quantitative analysis include cost-benefit analysis (Anas, 2020), (Casady et al., 2020), (West and Börjesson, 2020), regression-based analysis (Odeck, 2019), (Eliasson and Mattsson, 2006), and simulation studies (Beevers and Carslaw, 2005). Economic analysis of falling transportation revenues and the assessment of how and where mileage-based user fees can help the federal government have also been carried out (Institute for Policy Integrity, 2020). Meanwhile, a plethora of qualitative analysis has been conducted, such as public acceptance study (Rentziou et al., 2011), (Zmud et al., 2008), acceptance by elected officials (Hensher and Bliemer, 2014), equity impacts analysis (Hosford et al., 2021), and the interactions between land use policies and road pricing (Guo et al., 2011). Lessons learned from New York City's (NYC) first failed effort to implement road pricing, namely cordon toll provides a glimpse into the political economy of the times and what needs to change in order to make road pricing successful (Schaller, 2010). The Fix NYC Panel report from wide-ranging experts and stakeholder representatives proposes a gradual process for introducing road pricing in the central business district (CBD), beginning first with subway improvements, then levying fees among for-hire vehicles followed by charging trucks and then cars a congestion price for entering the CBD (Fix NYC Advisory Panel, 2018). In a recent study by Baghestani et al., the authors examine the impact of cordon pricing on three key equity indicators in New York City: traffic, public transportation access, and environmental concerns (2022). They find that the pricing strategies will disproportionately help to reduce the negative health outcomes of exposure to traffic related air pollution of residents of Manhattan’s CBD. In relation to equity, revenue recycling is important. Cohen D ’Agostino et al. find that reinvestment of RUC/toll revenue in public transit is key, though the adoption of public transit will be slower in areas where transit ridership is initially low, leading to an initial low return of on the investments(2020). The authors also find

that the more discounts and exemptions there are, the less efficient the system is and a variable pricing fee system is generally more equitable. Equity concerns have made RUCs historically politically unappealing, politicians worried about public acceptance of road pricing. Selmoune et al. suggested some ways to allay public concerns that include: share with the public what will change as a result of implementing pricing, including using results from a forecasting model, conduct trials to ascertain the effectiveness of road pricing, maintain "the practice that was showcased at the designing and trial phases to build the social trust of the public", and maintain a commitment to how revenues will be spent (2020).

While existing literature has extensively investigated the benefits of road pricing, most of these studies considered standalone cordon tolling or congestion tolling projects. Moreover, these studies generally focused on the impacts of road pricing programs in terms of addressing environmental pollution, congestion, and equity concerns, and not on the administrative, technical, or operational challenges of implementing the systems.

As mentioned earlier, one of the fundamental challenges of a RUC program is the relatively high cost of implementation compared to a traditional motor fuel tax - higher administrative, operational, and enforcement costs along with data privacy concerns. Some state agencies and metropolitan planning organizations (MPOs) responsible for planning implementation of a RUC program have conducted pilot studies to explore these challenges. For instance, California formed the Technical Advisory Committee (TAC) in 2014 to formulate recommendations for the design of RUC pilot projects and to investigate ways to reduce administrative costs. From conducting the pilot projects, TAC recommended simulating costs of collection and administration for multiple payment options, including online and mail payments (2015). Meanwhile on the technology front, Los Angeles Metropolitan Transportation Authority (LA Metro) conducted a proof-of-concept project to test the effectiveness of the mobile application in capturing toll transactions (2019). The mobile application leverages GPS technology to determine instances when the vehicles cross predetermined boundaries in order to assess tolls. The accuracy of this technology at capturing transactions is high at 99%, which indicates its viability as a technology option to reduce collection costs.

Overall, in the wave of states adopting RUC programs, it is important to thoroughly investigate the overlaps between existing tolling systems and a RUC program and to understand the impacts that these programs can have on each other. To that end, we reviewed several reports by government agencies and academics on this topic: evaluation of current tolling practices and RUC pilot programs. The main focus of the research here is to identify the key lessons policymakers can learn from current tolling practices and pilot studies in terms of technology challenges, operational costs, administrative concerns, and equity implications in order to implement RUC programs in the future. While the findings from the RUC pilot studies will be discussed in detail with the MCDA, major findings of the studies from academic papers on tolling practices and their interactions with road pricing are detailed in Table 1. A brief overview

of the literature on economic, environmental, and political challenges of RUC implementation will be discussed here since we do not dive into these topics in the MDCA.

Table 1. Summary of literature on road-pricing schemes.

Analysis categories	Author(s) and Year	Topics explored
Regression-based analysis	(Eliasson and Mattsson, 2006) (Odeck, 2019)	- Equity impact analysis of congestion pricing schemes - Estimation of tolling system's operational costs
Cost-benefit analysis	(Anas, 2020) (Casady et al., 2020) (West and Börjesson, 2020)	- General equilibrium analysis of benefits of congestion pricing schemes - Social cost-benefits analysis of tolling projects - Welfare analysis of congestion pricing schemes
Qualitative analysis	(Blythe, 1999) (Glavić et al., 2017) (Guo et al., 2011) (Hensher and Bliemer, 2014) (Hosford et al., 2021) (Iseki and Demisch, 2012) (Lehe, 2019) (Rentziou et al., 2011) (Santos, 2005) (Zmud et al., 2008)	- Impacts of land-use planning on congestion pricing - Political and public acceptance of road pricing schemes - Health-related outcomes of road pricing schemes - Synthesis of lessons-learned from existing congestion pricing schemes - Overview of manual collection and electronic tolling technologies - Multi-criteria analysis evaluating different tolling technologies' interoperability, efficiency, enforcement, traffic safety, and environmental impacts - Case studies on linkages between tolling systems' technological design and their relevant policy objectives

Research Methodology

Here we use a two-pronged analysis approach, where we begin with conducting semi-structured interviews and identifying relevant themes from our interviews. The second piece of our analysis leverage the thematic findings from the interviews to inform the evaluation criteria for the multi-criteria decision analysis (MCDA). This approach allowed us to seamlessly integrate the learnings from our expert interviews with findings from state-level RUC programs, and allows us to craft well-informed and timely policy recommendations to RUC program practitioners. Furthermore, to our knowledge, existing work on investigating the integration between tolling and RUC has not leveraged a combined method of qualitative interviews and MCDA. This aspect also makes our work well-positioned to address the needs of policy research on this front.

Stakeholders Interview

Over the period of July to October 2022, our team conducted 9 semi-structured interviews with tolling industry experts across the United States (list of institutions whose representatives were interviewed in Table 2). Semi-structured interviews are conversations where the interviewers set an agenda for topics of discussion, but they allow the interviewees a free range of response. It is often used in social science research to elicit perspectives and insights from the interviewees (Zeigler-Hill and Shackelford, 2020). Like Hardman et al.'s work on understanding the barriers to fuel-cell vehicles adoption, this project investigated a new area of transportation finance, the integration of tolling and RUC (Hardman et al., 2016). Therefore, we elected to conduct semi-structured interviews to gain in-depth knowledge from our experts. To conduct the interviews, we first designed a predefined set of questions as informed by our literature review on tolling systems. Then, we elicited feedback from Caltrans regarding the topics that were covered, including system operations, finances, data collection and handling, and technology etc.

Our recruitment strategy was based on contacts suggested by our funding agency: the California Department of Transportation (Caltrans), therefore we had a convenient sample of respondents, which was biased towards tolling experts from California. The interviewees were identified as experts in the tolling industry, since they have on average more than 10 years of experience working in the industry, and they represent a body of knowledge that spans many relevant topics in the tolling industry, including development/deployment, technology, pricing and payment, policy, and administration. Our interviewed experts have experience working in tolling in California, North Carolina, Oregon, and Utah, representing about 40% of the states evaluated in the MCDA.

The interviewees were contacted via email inviting them to a 45–60-minute interview. They were informed about the premise of the study in the email, namely what are some relevant lessons policymakers can learn from existing tolling practices and their viewpoint about RUC

programs. Furthermore, most of the interviewed experts have worked in US states that have implemented a RUC or have conducted RUC demonstrations, which makes them the ideal candidates for eliciting opinions on RUC-tolling integration. We also interviewed experts who operate tolling systems in states that have not yet implemented a RUC or held a RUC demonstration, such as Ohio and Texas. Even though these States have not implemented a RUC, the tolling experts are very well-aware and educated about the potential opportunities for collaboration between tolling and RUC, which makes them good candidates for our interview as well.

The interviews were conducted by a pair of researchers from the team, with the first author being the primary interviewer posing questions and collecting responses. At the beginning of each interview, the primary interviewer asked the interviewees about their background, roles, and responsibilities in their agencies. Then, the primary interviewer proceeded to ask the predefined set of questions. During the interview, the research team would follow-up with questions when they identified points raised by the interviewees that would benefit from more elaboration. All interviews were conducted via the online conference platform: Zoom, and most interviews lasted between 45 minutes to an hour. After we finished conducting the interviews, the research team transcribed them and reviewed the transcripts for accuracy. We then applied thematic coding on the transcripts, where we identified key themes that emerged from the interviews and grouped responses according to the key themes. In doing so, we deconstructed the transcripts into the following key themes: technology, operations, data, revenue leakage, equity, interoperability, and rate design. Once the key themes were formed, we collected data on interviewees' sentiments and positions around these key themes. The results from the interviews are presented in the Results section of this report.

Table 2. Organizations represented by the interviewed tolling industry experts.

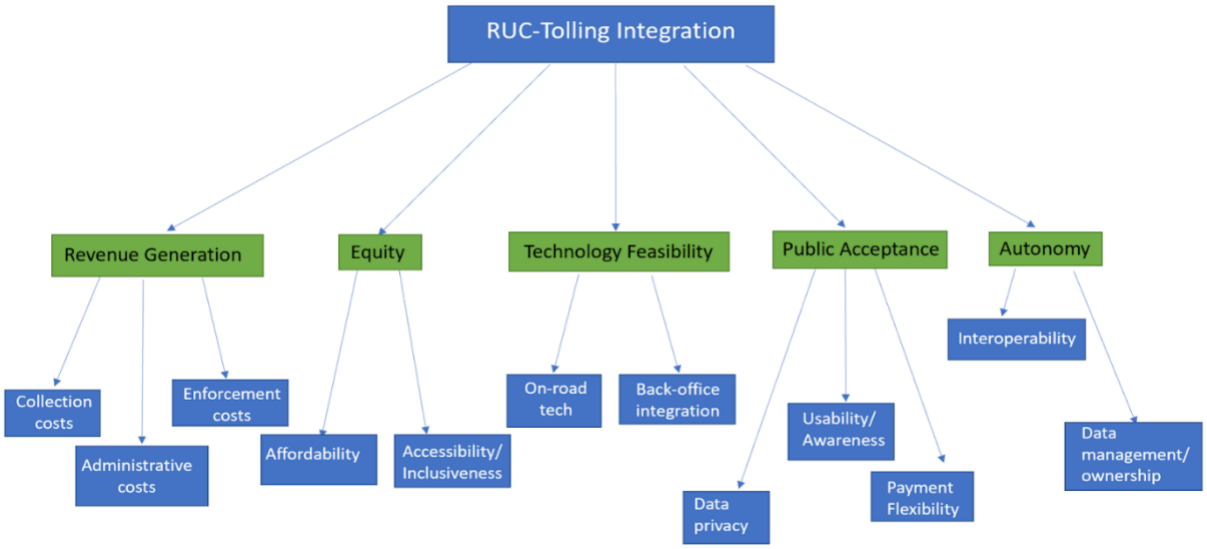
Organization	Organization Type	System Geographical Coverage	Date of Interview
International Bridges, Tunnel and Turnpike Association (IBTTA)	Industry association	N/A	July 15, 2022
The Transportation Corridor Agencies (TCA)	Tolling agency	Orange County, CA	July 20, 2022
AECOM	Consulting	N/A	July 22, 2022
WSP USA	Consulting	N/A	July 22, 2022
Metropolitan Transportation Commission (MTC)	Tolling agency	San Francisco Bay Area, CA	July 29, 2022
San Diego Association of Governments (SANDAG)	Tolling agency	San Diego, CA	August 5, 2022
Los Angeles County Metropolitan Transportation Authority (LA Metro)	Tolling agency	Los Angeles, CA	August 25, 2022
The Ohio Turnpike	Tolling agency	Northern Ohio	October 14, 2022
North Texas Tollway Authority (NTTA)	Tolling agency	Dallas-Fort Worth Area, TX	October 28, 2022

Multi-criteria Decision Analysis

Following the interview analysis, we conducted a multi-criteria decision analysis (MCDA) to evaluate how well the state-level RUC pilot projects conducted to date can integrate with tolling systems. MCDA is often employed by governmental agencies to evaluate alternatives in their decision-making process. By assessing how each alternative performs on the established criteria, MCDA helps decision makers establish preferences among different alternatives (Department for Communities and Local Government 2009). Additionally, MCDA also helps decision makers recognize the trade-offs among the alternatives, which is extremely crucial in the exploratory stage of tolling-RUC integration where policymakers from different states are learning from each other and tailoring RUC implementation to fit their states' transportation funding needs. To operationalize a MCDA, we first reviewed reports on RUC implementations

from states that have either implemented a full-scale RUC program or have conducted RUC pilot programs. These states include California, Colorado, the Eastern Transportation Coalition, Hawaii, Minnesota, Oregon, Utah, and Washington. By comparing the objectives from these reports to the key topic areas identified from our interviews with experts from the tolling industry, we constructed a value tree that reflects the shared objectives in a RUC-tolling integration (Figure 1). These objectives are revenue generation, equity, technology feasibility, public acceptance, and autonomy.

Figure 1. Value tree in the RUC-tolling integration context emphasizes the objectives that the integration is trying to achieve, including but not limited to revenue generation, equity, technology feasibility, public acceptance, and autonomy.



After identifying the objectives of state-level RUC programs and creating the value tree, we selected specific and measurable evaluation criteria for each value branch. These criteria were selected via identifying the commonly mentioned themes by our interviewees and identifying the overlaps between them and the findings from the reviewed literature on road pricing and tolling technologies as well as the reports on pilot RUCs. This allowed us to allocate the learnings from our interviews into criteria that we can then apply to evaluate all RUC programs to date. For instance, equity was a key theme mentioned by all interviewees and was highlighted in all state-level RUC programs that we reviewed. Understanding that this is an important area of consideration in both tolling and RUC, we identified the specific metrics used by tolling agencies to ensure equity. Another example: many interviewees emphasized the importance of affordability of toll payments and the accessibility of the tolling technology. To translate these findings to evaluation criteria for RUC, we measured how affordable a RUC program is and how accessible and inclusive it is. In evaluating a complex decision that involves multiple objectives, it is natural that some of these criteria are quantitative in nature, such as

collection costs, administrative costs, and enforcement costs, while others are qualitative like usability, payment flexibility, interoperability, etc. Keeping this in mind, we collected data on each of these criteria from the RUC pilot project reports for each of the abovementioned states and organized them in a performance matrix (Table 4) to be discussed further in the Results section.

The main purpose of a performance matrix is to present each alternative against the evaluation criteria in order to describe each alternative's performance on the criteria. For this project, the alternatives that are being evaluated are the states that have conducted a RUC pilot or have an operational RUC program, including California, Colorado, Eastern Transportation Coalition (i.e., Delaware, New Jersey, North Carolina, and Pennsylvania), Hawaii, Minnesota, Oregon, Utah, and Washington. By evaluating how well each state has performed on these criteria, we gained insights on how prepared each state is in terms of integrating their RUC program with tolling systems. The rubric of evaluation is presented in Table 3 below.

Table 3. Evaluation rubric for each criterion.

	Evaluation Rubric					
Criteria	n/a	1	2	3	4	5
Collection costs	No mentioning of collection costs	Some mention of collection costs in conjunction with administrative cost	Some mentions of collection costs but no quantitative estimates or indication of future research	Indicated an increase in collection costs and future investigation is needed	Provided specific actions to take for reducing collection costs	Provided estimates for collection costs
Administrative costs	No mentioning of administrative costs	Vague mentions of administrative costs, no examples or estimates provided	Some mentions of administrative costs but no quantitative estimates or indication of future research	Indicated an increase in administrative costs and future investigation is needed	Provided specific actions to take for reducing administrative costs	Provided estimates for administrative costs
Enforcement costs	No mentioning of enforcement costs	Vague mentions of enforcement costs, no examples or estimates provided	Some mentions of enforcement costs but no quantitative estimates or indication of future research	Indicated an increase in enforcement costs and future investigation is needed	Provided specific actions to take for reducing enforcement costs	Provided estimates for enforcement costs

	Evaluation Rubric					
Criteria	n/a	1	2	3	4	5
Affordability	No mentioning of affordability	Vague mentions of financial impacts of RUC	Only interested in state-level financial impacts of RUC, but not distributional impacts	Interested in analyzing the distributional impacts of RUC along the margins of household income, locale, driving patterns	Evaluated the financial impacts of RUC on different populations along the margins of household income, locale, driving patterns	Devised action plans to address distributional impacts of RUC on populations along the margins of household income, locale, driving patterns
Accessibility/ Inclusiveness	No mentioning of accessibility or inclusiveness	Vague mentions of accessibility or inclusiveness	RUC program is only open to selected drivers	RUC program is open to selected drivers with the objective of improving inclusiveness in the future	RUC program is open to all drivers with the goal to improve accessibility for populations with special needs (e.g., language, technology barrier)	RUC program is open to all drivers with additional mechanisms to improve accessibility for populations with different needs (e.g., technology barrier, language barrier)
On-road tech	No mentioning of on-road technology	Vague mentions of on-road technology	Focused on 1 mileage reporting option only	Focused on 1 mileage reporting options with the goal of expanding	Focused on 3-4 mileage reporting options	Offered a variety of mileage reporting options, including manual and automated options

	Evaluation Rubric					
Criteria	n/a	1	2	3	4	5
Back-office integration	No mentioning of back-office integration	Vague mentions of back-office integration	Lack of integration between on-road technology and data processing	Some integration between on-road technology and data processing, but not smooth	Leveraged account manager to provide data collection, processing, and invoices.	Leveraged account manager to provide data collection, processing, and invoices. Consider inter-agency data-sharing
Data privacy	No mentioning of data privacy	Vague mentioning of data privacy	Lack of standards or protocols to protect PII	Lack of State laws to protect PII	Devise data privacy laws to protect PII	Statutorily protected data privacy laws applied to RUC programs
Usability/ Awareness	No mentioning of usability/ awareness	Vague mentioning of usability/ awareness	Only RUC participants were educated on and exposed to RUC	Both RUC participants and the public were exposed to and educated on RUC	Only RUC participants were educated on and exposed to RUC and had a positive experience	Both RUC participants and the public were exposed to and educated on RUC and had a positive experience
Payment flexibility	No mentioning of payment flexibility	Vague mentioning of payment flexibility	Simulated invoices but not payment methods	Offered prepaid wallet as a payment option or flexibility in payment frequency	Offered prepaid wallet as a payment option and flexibility in payment frequency	Offered more payment options, especially accounting for unbanked or underbanked populations

	Evaluation Rubric					
Criteria	n/a	1	2	3	4	5
Inter-operability	No mentioning of interoperability	Vague mention of interoperability	Interoperability was not tested	Interoperability was not tested but indicated as a future research area	Tested interoperability with other States	Tested interoperability with other States and tolling agencies
Data management/ Ownership	No mentioning of data-sharing	Vague mention of data-sharing	Capable of sharing data between one governmental agency and account managers	Capable of sharing data between State agencies and account managers	Capable of sharing data across agencies within one State and account managers	Capable of sharing data across different State agencies and account managers

Results

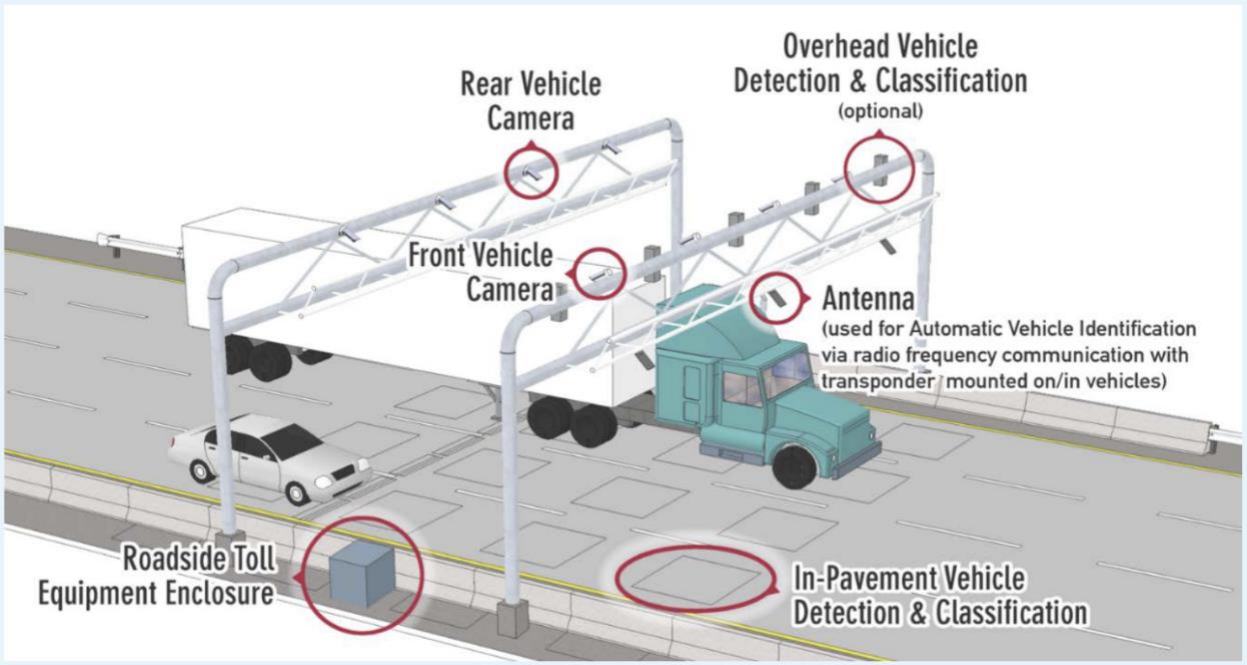
First, we discuss the main findings from the expert interviews that feed into the MCDA. Second, we summarize the results of the MCDA based on the themes shown in Figure 1 and the rubric given in Table 3.

Learnings from Expert Interviews

Technology

All of the tolling agencies that we interviewed are moving towards an open-road tolling system with all-electronic tolling technologies. At present, tolling systems rely heavily on ETC located in a traditional plaza configuration with toll booths that only allow passage when a toll is collected. The toll plazas have manually staffed cash-collecting booths or gated payment stations that accept electronic payments or both. Looking ahead, the goal of an open-road tolling system is to improve accuracy in capturing transactions, reducing the need for physical infrastructure, opening up road space, as well as to reduce the onus of collecting cash payments, which is operationally expensive. A study by the Texas A&M Transportation Research Group estimated that an open-road tolling system can offer 1.5 times (1,800 vehicles per hour) the flow rate of an ETC system located in the traditional plaza configuration (1,200 vehicles per hour). To do so, they will rely on all-electronic tolling technologies, which include radio frequency identification (RFID) reading technologies, such as gantries and sensors that are implemented at certain checkpoints in the systems and along the road. The RFID-reading technology can sense vehicles accessing the tolling systems via the RFID transponder that is in the vehicle. In the case where the drivers of the vehicles elect not to adopt the RFID transponder, all-electronic tolling systems would leverage camera equipment to capture vehicles' license plates. This image-capturing technology allows tolling agencies to collect the unpaid tolls after the fact, which will be elaborated upon in the latter section. Some of the tolling agencies that we interviewed manage express lanes, in which case the RFID-reading technology and the camera equipment are implemented along the entire coverage of the express lanes in order to capture the distance traveled by vehicles in these lanes. Figure 2 shows a typical open road tolling system with RFID and license plate recognition technology.

Figure 2. A typical Open Road Tolling System.



In terms of the costs of all-electronic tolling technology, depending on the system's size and coverage, the estimated costs range from $25 to $55 million with an expected lifetime of 10 years. The range of costs was collected from the North Texas Tollway Authority (NTTA) and the Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area. The NTTA implemented an all-electronic tolling system in 2020 and processes about 2.6 million transactions per day. Meanwhile, the MTC is in the process of converting the seven California state-owned bridges to all-electronic and open-road tolling, and the agency has 2 million active accounts each month. On a per-transaction basis, the cost of technology implemented to capture a transaction via a RFID transponder ranges from 10 to 20 cents. This is comparably lower than the cost of capturing a transaction via image capture of license plates at around $1 per transaction. Even though the agencies did not provide us with an estimate of the per-transaction cost of collecting cash payments, they all agreed that the cost would be much higher than using RFID transponder or image capture of license plates. An expert from the San Diego Association Governments (SANDAG) stated *"everybody is working hard towards eliminating cash payment…. handling cash is very, very expensive everywhere*". In moving towards an open-road tolling system, agencies believe that they can improve the cost-efficiency and accuracy of their toll collections.

Looking ahead, some agencies have suggested the possibility of leveraging in-vehicle telematics which may be programmed to communicate with RFID-reading technology of the tolling system to capture vehicles when they use the system. Extending this application to RUC, vehicles' miles driven on tolling systems can be captured by tolling agencies which would help reduce the need to implement a different set of technology for RUC implementation. However, if the vehicles do

not drive on tolled roads or does not have RFID-transmitting technology, then additional technology solutions would need to be implemented to capture these miles for RUC. On the other hand, there currently exists a barrier for tolling agencies to leverage in-vehicle telematics because they are proprietary to the auto manufacturers. Depending on future policy directions and business cases of RUC implementations, more collaborations between tolling agencies and auto manufacturers may be encouraged in order to reap the benefits of reducing technology redundancy.

Operations

For most tolling agencies, the implementation and the operation of the system are often contracted out to professional tolling system integrators. These system integrators design, build, and implement the technology; they also manage the transactions on the customer-facing front, colloquially known as the "back office". Most tolling agencies select their system integrators via a competitive bidding process. While the initial implementation costs are provided in the previous section, there are still maintenance costs associated with operating the systems. From our interview with the Ohio Turnpike and the NTTA, their annual maintenance costs of the back office are about $3 and $5 million dollars, respectively. The back-office handles transactions by either directly matching the associated RFID to existing accounts or reviewing the license plates captured and working with the Department of Motor Vehicles (DMV) to identify the vehicle owners. As stated by an industry expert with WSP, the process works such that "*everybody that travels through has to use a toll tag or be billed later*". The per-transaction cost of RFID transponder is much lower than that of image capture because linking an RFID transponder directly to an existing account reduces the manual labor that is sometimes required to verify license plate images when images are unclear and to obtain vehicle owner data from the DMV. As described by the Chief Executive Officer of TCA, "*The cost does increase at that point, because the first thing we have to do is to work with the DMV to get information from them on who the registered owner is, and then, we've got to go into a mailing process*". Even though some tolling agencies have image capture systems that review images and assign a confidence score automatically, there is still a substantial amount of manual labor that is associated with this kind of transactions.

On average, the tolling agencies that we interviewed manage 2 to 11 million accounts with a daily volume of transactions ranging from 350,000 to 2.5 million. For instance, the Transportation Corridor Agencies (TCA) manages 2 million accounts and processes 350,000 transactions daily, while the NTTA manages 11 million accounts and processes 2.5 million transactions daily. The staffing requirements for managing the back office range from 40 to 400 individuals, depending on the size of the tolling system and the volume of transactions. As a tolling system moves towards all-electronic, the staffing requirement in the back office grows. As mentioned by the Chief Technology Officer of the Ohio Turnpike who will be implementing a new system in 2023, "*that whole structure [of all-electronic tolling system] increases the staff that you have to have in the back office. Today we have eight individuals in our back office.*

We're projecting in the next ten years that number will grow to thirty-six". While the back-office staffing requirement grows, the front-facing toll collectors would decrease because most of the toll collection would be done either electronically from the toll accounts or via other payment methods which will be discussed in detail in the "Equity section".

To reduce operational costs, tolling agencies are in favor of adopting technology that would reduce as much manual labor and technical error as possible, which includes promoting the adoption of RFID transponders to their users. Our expert from the NTTA stated "*we want to get you into a tag, if you call us, we will reduce most of those fees to get you to open up a toll tag account*". Currently, the average percentage of RFID transponders adoption is around 75% for the interviewed agencies. One of the reasons for users rejecting RFID transponders is the privacy concerns around being tracked by the agencies. To that end, tolling agencies adhere to stringent state-level laws around the management of personally identifiable information (PII) and do not share this data without a warrant from law enforcement. In addition, some tolling agencies proposed the offering of a low-privacy and a high-privacy option in the context of RUC implementation. In this case, the high-privacy option does not require drivers to share their location, time of use etc., while the low-privacy option would require more tracking in order to ensure that drivers are accurately being priced for their use of the road. With the current RFID technology in all-electronic tolling systems, the ability to track where vehicles are going on the tolled roads is possible. This may be leveraged by RUC implementation to tabulate a portion of the miles that vehicles drive, but it would not be sufficient to cover all of the miles driven within a State jurisdiction. To illustrate this point further, California currently has 870 miles of tolled roads, which accounted for about 0.5% of all public roads in the State (Caltrans 2022). When applying the technologies from the tolling industry to the operation of a RUC, we need to be aware of this difference in the scale of coverage and devise realistic collection methods for RUC.

Data

From tolling agencies' perspectives, the most basic data that needs to be collected from the users of their facilities are RFID transponder data which links a vehicle to their account. The PII associated with the account includes the account holder's name, address, vehicle license plate, make and model, and the payment information. The PII is managed by the back office of the interviewed tolling agencies. If the vehicle does not have an RFID transponder, then tolling agencies leverage their license plates to identify the owner of the vehicle for billing purposes. Some tolling agencies also capture the weight, the height, and the number of axles of vehicles to determine their weight class and the appropriate toll rates. For instance, the Ohio Turnpike captures all the above pieces of data for all vehicles entering its toll gates. For agencies that manage distance-based tolling, they collect data on the checkpoint of which vehicles access the toll facilities and the checkpoint of which they leave the facilities. This information is then used to estimate the distance traveled on the facilities and the appropriate toll. While capturing the transactions, some tolling agencies would also capture auxiliary data such as the date, time,

and speed of the vehicles. While the date and time data would be important for the tolling agencies to verify the transactions, the speed of the vehicles is non-essential to their job function. Many tolling agencies have explicitly stated that their main objective is to collect the tolls that are due to them, and not to enforce speed limits on their facilities.

Data Privacy

As mentioned in the previous section on privacy concerns, tolling agencies have compliance standards around data handling in order to mitigate these concerns. The back office of the tolling agencies is PCI-compliant which means that they adhere to the Payment Card Industry (PCI) Data Security Standards around the handling of credit card information. The standards mandate that the agencies do not store credit card information directly, instead, they use tokenization to access a secure database. They are also required by some State laws, such as the case in California, to purge the data within 30 days when it is no longer needed. While industry standards and State privacy laws are institutionalized to protect tolling customers' data, some customers would still have concerns around privacy, especially at the early stages of the program. For instance, the Mobility Planning Manager from MCA recalled when their agency first issued RFID transponders in the mid-1990's, "*many customers were worried about being tracked and how their data were being handled*". To address these initial concerns, the MCA "*distributed Mylar bags with the RFID tags, so that people could then put their tag inside a Mylar bag and not be tracked. You could just take it out at the bridge read point*". Even though these concerns have faded away as tolling customers became more familiar with the technology and felt confident in the protection of their personal information, it is important to recognize that initial surge of privacy concern is valid, and agencies would need to be prepared to address these concerns.

On the other hand, in looking forward to potentially integrating RUC with tolling, on the data front, some tolling agencies see an opportunity to collaboratively improve data access and quality. Specifically, when tolling agencies handle transactions that require linking vehicles' license plates to the owner via the DMV, the data access and quality are not standardized. The CEO from NTTA found that "*sometimes things as simple as the DMV making changes or adding data fields that they then send to us are things that we don't quite understand but could eventually help us tremendously*". With the implementation of RUC, there may exist an opportunity to ensure that business rules and processes are in place for implementation agencies to obtain accurate data from the DMV efficiently. Furthermore, building a flexible and secure database among the implementing agencies of RUC would boost cost-efficiency of the program. Lastly, this would also help reduce leakage in toll collection which is discussed more extensively in the following section.

Revenue Leakage

When moving to an open-road and all-electronic tolling system, agencies are concerned about leakage in toll collections because they move from a pay-now model, where users of their facilities pay a toll before accessing the facility, to a pay-later model, where users access the facility first before paying for the use. The CTO of Ohio Turnpike described the open-road tolling payment model as "*come into our store and you don't necessarily have to identify yourself. Take whatever you want, and we'll chase you down later and figure out how you're going to pay for it*". This model poses incentives for users to evade tolls, especially those who do not have an established account with the tolling agencies. For instance, some tolling agencies find that users intentionally hide their license plates to evade tolls. Without accurate license plate data, tolling agencies are unable to issue invoices to these users; these unidentified violations consist of about 6% of total transactions of the NTTA. Currently, tolling agencies partner with law enforcement to patrol their facilities and to enforce license plates laws in their respective States. However, this is a retroactive solution, and it is also administratively costly to execute.

Another form of leakage occurs when violators refuse to pay their invoices; these uncollectible invoices account for about 8% of total transactions on the NTTA system. Even though tolling agencies can work with the DMV to put holds on vehicle registrations, they do not have direct authority over the vehicle owners to make them pay their tolls. Especially in the case when vehicles are sold or the registrations are transferred from the violators to someone else, tolling agencies lose the authority to pursue the uncollected tolls. In total, both forms of leakage account for approximately 14% of total transactions on the NTTA tolling system, which could amount to a loss of revenue in the order of millions of dollars annually. To mitigate the impact of leakage on revenue, tolling agencies encourage their users to adopt RFID transponders, because these established accounts are usually backed by credit cards. However, the unbanked and underbanked populations would not be able to back their accounts with credit cards, which may pose an access issue that will be discussed in the following section. The leakage rate of RFID transponder transactions is less than 1%. In applying this insight to RUC implementations, tolling agencies experts recommend a "pay now" model, where users should be charged a certain amount of money based on their expected usage of the road. A true-up can be conducted on a monthly, quarterly, or annual basis to ensure that users are being fairly charged for their use of the roads. While this approach would reduce leakage, it would pose equity concerns as low-income populations might be financially burdened by such a model. More discussion on equity concerns will be presented in the following section.

Equity

One major value that tolling agencies support is the "user-pays" principle, whereby if a driver uses a facility, then they should pay for their portion of the cost that was incurred to build and to maintain that facility. Accessing the toll facilities, whether to bypass traffic or to cross a bridge, is a service that one should pay for. If one does not wish to pay for this service, one can

choose not to use it. Under this framework, tolling agencies view that the fairest way to fund transportation infrastructure is via a user fee, such as a RUC. Samuel Johnson from the TCA emphasized that "*it's truly a user fee model. You use the road, you pay, so it is a direct payment for the service you received*". While the "user-pays" principle may espouse equality and fairness in paying for one's fair share of road usage, it overlooks the fact that populations of different income levels may have different abilities to afford such payments. Especially in the context of RUC where alternatives to not using the roads may not exist for some populations or would significantly reduce people's mobility and quality of life. For instance, low-income populations may not be able to afford paying upfront for their annual expected road use, which is in the hundreds of dollars, if they drive around 12,000 miles each year and the RUC rate is about 2¢/mile. When designing a RUC program where the alternatives to driving on public roads may be limited, it is important to consider the financial impacts on different income groups and devise assistance programs that equitably address these impacts. One potential solution to this would be to implement a flexible payment frequency as part of RUC enrollment, so drivers can determine the payment frequency that works best for them and plan accordingly.

Another aspect of equity that arose in the interviews is ensuring that the technology of an all-electronic tolling system does not hinder the unbanked and underbanked populations from accessing the system. While the tolling industry is moving towards the model of RFID transponder and established accounts backed by credit cards, there still needs to be other ways for the unbanked and underbanked populations to pay their tolls. Some tolling agencies currently allow their facility users to pay tolls with cash at physical locations across their service area. In addition, LA Metro allows users of their toll roads to pay via a prepaid card which they can also use to pay for transit services. "*Rather than just saying we need your credit card otherwise you do not have access to the system. To provide access to different people, they came up with that replenishment with cash at 7-11 stores nationwide, so that's a plus*", said Industry expert from AECOM. Furthermore, the NTTA partners with a cell phone carrier to allow the transfer of tolls to users' monthly phone bills. This helps lower the barriers for unbanked or underbanked populations to pay their tolls, since they can pay them along with their phone bills. By streamlining the payment process for unbanked and underbanked populations, tolling agencies aim to address equity concerns around toll collections and to reduce leakage in revenue collection. These alternative payment methods are key to addressing the technology burden that all-electronic tolling may place on unbanked or underbanked populations, because it ensures that they have access to the tolling system while reducing potential leakages from toll evasions. Offering multiple payment options and consolidating the utility services that users need to pay into one channel would be highly important to the implementation of RUC.

Interoperability

Interoperability in the context of tolling means the ability for multiple tolling agencies to exchange data on transactions and vehicles in order to accurately recuperate the tolls from their users. The interoperability that exists in tolling takes two forms: one form is that multiple

agencies agree to synchronize their roadside technologies and send transactions to one back office. Under this model, users of these tolling facilities would not notice any difference in accessing the facilities and paying for their tolls. For example, the MTC in the San Francisco Bay Area currently operates its bridges and express lanes under this model. One key characteristic of this model of interoperability is that users of the facilities would not notice any difference among the different agencies that manage these facilities because the technology and the billing are uniform. Another model is the interoperability tolling hub model, where different tolling agencies can have different technologies and back offices, but they coordinate transactions that occur on their facilities such that the user of the facilities only pays one agency for all the tolls. For instance, in the E-Z pass tolling interoperability hub, there are 35 tolling agencies that span across multiple Eastern, Southern, and Midwest States. All these tolling agencies may have different roadside technologies. However, they conduct peer-to-peer file transfers daily to tabulate transactions that happen outside of their jurisdiction and then they process the billing of these transactions. Under this model, users of different tolling facilities may notice the differences in technology or signages of the systems among different agencies, but they would only receive one bill from their home tolling agency.

Data-sharing is a prerequisite for tolling interoperability because a large amount of data on transactions and user information needs to be shared in a timely manner among agencies in order to reap the efficiency benefits of interoperability. Brian Kelley from the Ohio Turnpike stated that "*you've got to get everybody in agreement, and you have to get all of their different technology systems by which they collect tolls to be able to process those files and reconcile them through one system*". As mentioned by a few experts, California currently has stringent laws around data-sharing across State boundaries which may hinder itself in becoming interoperable with other States. In a similar vein, if tolling were to become interoperable with RUC in the context of California, the ability to share data among tolling agencies within the State is crucial. Furthermore, there exists an opportunity to leverage the existing account management and customer service expertise from tolling agencies to manage the fee administration and collection fronts of RUC. For instance, the account holders in the NTTA tolling system covered about 70% of the registered vehicles in the Dallas-Fort Worth Area and surrounding metroplex, which span across 26 counties. The geographical reach of existing tolling systems coupled with their expertise in account management puts them in an ideal position to collaborate with RUC implementation on the back-office operations.

Rate Design

All the interviewed tolling agencies agree that the primary goal of toll rate design is to generate enough revenues for the maintenance and operation of the systems. Out of the experts who we interviewed, the TCA, the NTTA, and the Ohio Turnpike pride themselves on being able to do so without relying on any tax dollars, which ensures the reliability and sustainability of the funding source. For example, the CEO of NTTA stated that "*Since 2017, [the NTTA] has invested anywhere from $6 to $8 billion dollars, I should say, in building infrastructure here that has no*

tax dollars associated with it". For express lanes, the toll rate also needs to accomplish the objective of reducing congestion and ensuring that the minimum average travel speed of 45 miles/hour is met. In some cases, agencies implemented dynamic toll rates on express lanes which adjust to traffic conditions, such as the express lanes managed by the MTC. For tolling agencies, such as the TCA, that leveraged the private equity market to obtain the seed funding for the construction of their systems, they are under the obligation to generate revenues and to pay back the bonds which may influence their toll rates to be higher. However, even these tolling agencies agree that it is important to keep the facilities affordable and accessible to all.

Another area of consideration is implementing weight-based toll rates because vehicles of different weights pose different wear-and-tear effects on the road. Currently, some tolling agencies identify the number of axles on a vehicle and classify the weight class of the vehicle based on this characteristic. The Ohio Turnpike has the following classification: "*A class one vehicle would be a passenger car. A class two would be a vehicle that has three axles, which is a truck or a car with a trailer and another set of axles. Class three, four, or five would lead up to a semi-truck*". For RUC implementation, rate-setting is a crucial piece of policymaking. This intricate act would need to balance many factors, including revenue generation to replace the gasoline tax and equity impacts on populations of different income levels and mobility needs. For instance, in a RUC implementation, the agencies' prime objective is to recuperate enough funds to replace revenues from the gasoline tax. However, there are other policy objectives, such as congestion reduction, air pollution reduction, and transit improvements that can be addressed by tweaking the RUC rate. In other words, the RUC rate for an area that is heavily impacted by the tailpipe emissions of heavy-duty vehicles may be set higher in order to discourage travel through that area. One of the most important takeaways from tolling in terms of rate design is to set clear and defined goals for what the rates aim to accomplish, while devising strategies to mitigate the disproportionate financial impacts on low-income populations. Future research in this area is extremely important and timely.

Learnings from the Multi-criteria Decision Analysis

The MCDA constitutes of evaluating existing RUC programs and pilot programs in the US based on the key characteristics and evaluation criteria identified in the value tree (Figure 1) and the rubric we developed (Table 2) to analyze how well prepared each state is to implement and integrate RUC with tolling. Table 4 gives the evaluation of eight RUC programs with '5' indicating the program has well-accounted for the characteristics in their RUC program design to integrate with tolling while '1' indicating that the characteristic was considered but not adequately. 'N/A' indicates that there was no data regarding the characteristic in the report we evaluated.

Table 4. Evaluation of each State's RUC program or pilot against the criteria identified in the value tree above.

	Revenue Generation			Equity		Technology Feasibility		Public Acceptance			Autonomy	
	Collection Costs	Administrative Costs	Enforcement Costs	Affordability	Accessibility/ Inclusiveness	On-road Tech	Back-office Integration	Data Privacy	Usability/ Awareness	Payment Flexibility	Inter-operability	Data management/ Ownership
California	3	5	4	3	3	5	4	5	5	3	4	4
Colorado	3	3	4	3	4	4	5	4	5	3	3	3
Eastern Transportation Coalition	4	4	4	5	4	4	5	4	5	2	5	5
Hawaii	4	4	3	4	4	5	4	5	5	3	2	2
Minnesota	3	3	3	3	2	3	5	4	4	2	4	3
Oregon	3	4	4	4	4	3	5	4	4	3	4	4
Utah	4	4	4	4	3	4	4	5	5	4	3	4
Washington	4	5	4	3	4	5	5	4	4	3	4	5

Revenue Generation

To evaluate the revenue generation capacity of each State's RUC pilot or program, the following criteria are evaluated: collection costs, administrative costs, and enforcement costs. Keeping in mind that most of the RUC implementations to date have been demonstration projects, there are limited capacities in generating revenue from RUC. Therefore, most States either provided quantitative estimates on costs, or they provided qualitative descriptions on how to reduce these costs. In terms of administrative costs, all the States agreed that administrative costs of RUC would be much greater than that of the existing motor fuel taxes. This is largely due to the increase in the number of collection points, as explicitly mentioned in the Minnesota RUC report. In contrast to the low administrative costs of collecting motor fuel tax, which is about 0.5% of revenues, the administrative costs of RUC ranges from 7% to 12%. For instance, Washington estimated that the administrative costs of a RUC were about 7% and 12% for the manual odometer reporting option and the electronic odometer reading device, respectively (2020). Meanwhile, California also provided a similar range of estimates on the administrative costs of RUC, ranging from 5% to 10% (2017). The higher end of the estimate reflects the high upfront costs in collecting a small percentage of the State's driving populations. As the RUC program transitions to replace motor fuel tax for all drivers, the administrative costs would be expected to decrease to the lower end of approximately 5% of total revenue.

To narrow the gap between the administrative costs of RUC and that of motor fuel tax, many States have proposed a number of solutions that are tailored to the State's existing program. For instance, Hawaii conducts inspections of vehicles as part of their annual registration. Integrating RUC into the annual vehicle inspection would streamline the mileage data collection process which would reduce administrative and collection costs. Similarly, California has expressed interest in integrating manual RUC mileage reporting with smog checks which are required annually for vehicles that are more than eight model-years old. On the other hand, Minnesota has approached this issue differently by leveraging in-vehicle telematics to directly capture and report mileage driven by vehicles. The integration between tolling and in-vehicle telematics is also an area of interest that many agencies would like to explore. Joining efforts on this front could potentially reduce the cost barrier to accessing these data and build a stronger case for auto manufacturers to share these data with tolling and RUC agencies. Given the characteristics and existing infrastructures of each State, they should have the autonomy to design and to implement a RUC program that not only minimizes costs but also works well for their residents.

Equity

The equity considerations from each State's RUC program are evaluated by the affordability and inclusiveness of the programs. In this context, inclusiveness is defined as how well the program accommodates drivers of different socioeconomic backgrounds, travel behaviors, and

vehicle classifications. For instance, one major concern that was brought up by many States was whether the implementation of RUC would disproportionately and negatively impact rural drivers who tend to travel longer distances to access required services. This concern was addressed by many States' RUC programs via recruiting RUC participants from a range of geographies and evaluating the difference between their RUC payments and their gasoline tax payments. For instance, California RUC pilot recruited a total of about 5,100 participants from both rural/ agricultural and urban/suburban communities and from different income levels, ethnicities, genders, and age groups (2017). Similarly, the RUC pilot program conducted by the Eastern Transportation Coalition across Delaware, New Jersey, North Carolina, and Pennsylvania also recruited about 380 participants from both rural and urban geographies (2022). By evaluating the financial impacts of the RUC program on rural drivers, the Eastern Transportation Coalition found that rural drivers are likely to pay less under RUC because they tend to drive less fuel-efficient vehicles which amounts to higher gasoline tax payments. The estimated range of difference in annual payment between RUC and gasoline tax is about $18 for rural drivers.

Another area of equity consideration is levying RUC on battery electric vehicles (BEVs) drivers while requiring them to pay the enhanced registration fee, an annual additional flat fee of $100 (California Vehicle Codes 2017). To avoid double-charging BEV drivers, Utah and Hawaii have waived the enhanced registration fee for BEV drivers participating in the RUC program and devised a cap of RUC at the average annual gasoline tax payment, respectively. In a similar vein, all the other States have emphasized the need to devise a refund mechanism for the gasoline taxes that drivers paid while our transportation funding transitions from motor fuel tax to RUC. In addition to considering the fuel type technology in devising RUC, vehicle weight is also an important dimension of equity consideration. The Eastern Transportation Coalition and Washington specifically raised the need to structure RUC rates based on vehicle weights, because heavier vehicles pose more wear-and-tear on roads. This weight-based rate design was also an important issue mentioned by a number of tolling agencies that we interviewed, including the Ohio Turnpike which implemented weight-based toll rates on its systems. Because of the recruitment strategies, most States had pilot participants who are from different income levels, geographies, and drive vehicles of different vehicle fuel efficiencies. While Minnesota's RUC program is technologically advanced, it was limited to shared mobility fleets only. Therefore, it was unable to assess the financial impacts of RUC on different populations. As emphasized by the interviewed tolling agencies, equity considerations are extremely important in designing a RUC program that will impact millions of people. The lessons learned from tolling on equity considerations can be applied to RUC, however, there remain unique challenges such as rate-setting and the considerations of non-internal-combustion-engine vehicles which would need to be addressed.

Technology Feasibility

To evaluate how feasible the technology integration is between RUC and tolling, we focused on the on-road technology and the back-office integration. Many States offer a variety of on-road technologies for participants and enrollees to choose from. All the States, except for Minnesota, offered multiple mileage-reporting options to their RUC participants, including GPS-enabled OBD, non-GPS-enabled OBD, smartphone-based apps, manual odometer image captures, and in-vehicle telematics. This not only allows the States and the account managers to test out different on-road technologies, but also provides participants with options that best suit their travel needs. Specifically, manual odometer image capture is a high-privacy option which provides RUC participants with an additional level of privacy. Overall, California and Washington offered the highest number of mileage reporting options, with California offering six options and Washington offering five options. From its 2018 RUC pilot, Washington found that about 56% of its 2,000 participants chose either the GPS-enabled or non-GPS-enabled OBD options, while about 30% chose the manual odometer image capture option, with the remaining 14% choosing the smartphone-based apps. On the contrary, about 60% of Hawaii's RUC pilot participants selected the manual odometer image capture option, while 30% and 10% opted for GPS-enabled and non-GPS-enabled OBD options, respectively. This difference in preferences for on-road technology emphasizes the geographical differences and the needs to tailor to each State's residents and its existing processes that bring the most familiarity to both the RUC enrollees and the staff. By offering a variety of reporting options, the States learned the reporting options that work best for their RUC participants.

Ideally, one of the capabilities of RUC on-road technology is to distinguish whether the miles were driven inside or outside a State's boundary because only miles driven inside a State should be subject to that State's RUC. From the RUC pilots and programs, Colorado and Oregon learned that GPS-enabled OBD can effectively distinguish in-State and out-of-State miles driven by a vehicle. In addition to the advantage of distinguishing between in-State and out-of-State miles driven, GPS-based OBD can also integrate with tolling systems to collect tolls. For instance, the Eastern Transportation Coalition conducted a tolling-RUC integration pilot on passenger vehicles in 2021 by recruiting about 200 existing tolling customers in Virginia (2022). From the pilot, they learned that GPS-enabled OBD is successful at collecting tolls when the tolling systems are in the following configurations: single-directional toll plazas that are at least 8 feet from other traffic flows or toll plazas and cumulative tolls collected as vehicle passes under gantry. This result demonstrated that it is technologically feasible to integrate RUC and tolling using existing on-road technologies. On the other hand, the nation-wide truck pilot project conducted by the Eastern Transportation Coalition from 2020 to 2021 implemented the use of in-vehicle telematics to track mileage driven. The in-vehicle telematics on heavy-duty trucks required professional installation which prevents any potential odometer fraud and provides accurate mileage data. Future directions on tolling-RUC integration should consider

leveraging both in-vehicle telematics and GPS-enabled OBD to test more complex tolling configurations and business rules.

Besides on-road technology to collect mileage data, back-office operation of RUC programs is also crucial in processing transactions, consolidating invoices, and providing customer services to the participants. Because of the similarities in the requirements and capabilities between a tolling system's back office and that of the RUC program, the Eastern Transportation Coalition, Oregon and Washington have expressed interest in integrating the back-office operations between tolling and RUC. From the interviews we conducted with tolling agencies, all of their back offices are contracted out to third-party operations. Similarly, the RUC program's back offices are also operated by third-party account managers who interface with RUC participants to collect their data, to process their transactions and invoices, and to answer any customer service-related questions. An essential component to back-office integration in RUC, whether it is with tolling agencies or with other governmental agencies, is creating technical infrastructures for data-sharing. Specifically, Utah is developing and testing secure data linkages between its operational RUC program and the DMV by leveraging the existing technical expertise of its third-party account managers (2021). Hawaii is pursuing a similar integration on the data-sharing front between its RUC program and its DMV (2022). State-level interests and efforts in investigating the technological feasibility of different on-road technologies and back-office integration would help reduce costs and administrative burdens of future RUC implementations.

Public Acceptance

Public acceptance of a RUC program hinges on multiple aspects, including but not limited to data privacy, usability of the system, and flexibility of payments. While payment flexibility was emphasized by tolling agencies, especially in providing means for unbanked and underbanked populations to pay tolls, the RUC programs and pilots assessed were voluntary and only simulated payments. Due to the lack of concrete financial transactions, the extent to which States have addressed payment flexibility is around the timing of payments. For instance, Hawaii found that about 52% of their 39,600 survey participants prefer quarterly or monthly RUC payments instead of an annual payment (2022). Utah supported the idea of providing flexibility in payment frequency, stating that a statewide implementation of RUC would entail an annual lump sum payment in order to reduce administrative costs associated with more frequent payments (2021). On the front of payment methods, California, Colorado, Minnesota and Utah tested the method of a prepaid wallet, managed by the third-party account managers. From reading the reports, it is unclear whether unbanked or underbanked populations could access the prepaid wallet method. This remains an area of concern which needs to be addressed as States expand their RUC programs.

Another key component to boosting public acceptance of a RUC program is ensuring data privacy. To accomplish this, States have focused their efforts on these two fronts: distancing the

State governments from handling PII and ensuring the highest security standards and management procedures of PII. Besides Hawaii, all the other States have considered the heavy involvement of a third-party account manager as part of their future RUC implementation. As identified by Colorado's RUC pilot participants, there was a considerable amount of concern on providing their PII to governmental agencies (2017). To address this, many States including California, Colorado, the Eastern Transportation Coalition, Minnesota, Oregon, and Utah have explicitly expressed that only aggregated and anonymized data would be shared with their State agencies. By placing the responsibility of collecting and managing PII on the third-party account managers, the States need to enact and enforce the most stringent data privacy laws for the RUC program. For instance, California has stated that the data collected from the RUC program would be protected pursuant to the statutorily mandated privacy provisions in SB 1077 (2017). Coupling high standards of data management and data security with the stringent and statutorily mandated data privacy provisions, the States can provide the necessary peace-of-mind to RUC participants.

On the usability and awareness front, we evaluated the efforts that the States have taken to educate the public about RUC via surveys and focus groups. In addition to conducting RUC pilots, education and outreach efforts on RUC to the general public are essential to promoting the public acceptance of this new transportation funding mechanism. Through an extensive outreach program, Hawaii surveyed about 49,500 residents, and about 80% of residents indicated that they had a high level of initial understanding of motor fuel tax as a source of transportation funding (2022). In contrast, Colorado surveyed about 500 participants in 2016, prior to the start of the RUC pilot project, and found that about 70% of survey participants are unfamiliar with transportation funding sources. Similarly, the Eastern Transportation Coalition also found that out of its 2,000 survey participants across Delaware, New Jersey, North Carolina, and Pennsylvania, about 70% of them are not familiar with RUC (2022). The differences in the initial public awareness of RUC across States further highlight the importance of educational and outreach efforts on RUC. Except for Hawaii residents, the residents from other States were not familiar with RUC or gasoline tax as a means to fund transportation. Despite that, most of the RUC pilot participants became more aware of RUC and are supportive of it replacing the gasoline tax. Specifically, 83% of California's RUC pilot participants were satisfied with the pilot (2017). Similarly, the Eastern Transportation Coalition found that over 90% of passenger vehicle pilot participants were satisfied with the program (2022). This further demonstrates the effectiveness of conducting RUC pilot projects as a way to educate the general public on transportation funding.

Autonomy

As demonstrated in the evaluations of the above criteria, geographical differences largely influence how States approach RUC implementation. Through conducting pilot projects, each State learned which technology options, reporting options, and administration of RUC are best suited for their residents. Recognizing that State-level RUC implementation would not be "one-

size-fits-all" and that States should have the autonomy to design and to implement their RUC programs, we evaluated how prepared they are in collaborating with other States to process interstate travel and how robust their operations and technologies are in facilitating interstate and inter-agency data transfer, sharing, and management. Drawing from lessons learned from tolling agencies, we defined interoperability in the context of RUC implementation as the ability for multiple RUC programs to exchange data on transactions and vehicles in order to accurately recuperate the payments from their users. As demonstrated by the RUC interoperability pilot between Oregon and Washington, a financial clearinghouse or interoperability hub model would be best suited for RUC. Under this model, each State can have different technologies and back offices, but they coordinate interstate travel such that the drivers would pay for their RUC payments to their home State only. This model was tested between two pairs of Western States: Oregon-Washington and California-Oregon by leveraging GPS-enabled OBD. While the technologies of interoperability hubs are feasible, one of the challenges that Washington expressed was the administrative burden in determining the amount and the location of fuel that each vehicle purchased in order to process refunds (2020). Additionally, California found that it was difficult to process refund requests for interstate travel for drivers who did not use GPS-enabled OBD, since it required more supporting evidence to demonstrate their inter- vs. intra-State travel (2017).

Given the multi-State nature of the Eastern Transportation Coalition, their passenger vehicle pilot project recruited participants from Delaware, New Jersey, North Carolina, and Pennsylvania from 2020 to 2021. The RUC system for these 383 participants across four States was uniform in design and implementation, which mimics another form of interoperability as observed in some of the interviewed tolling agencies (2022). In this form of interoperability, multiple States agree to synchronize their on-road technologies and send transactions to one back office for processing. Under this model, RUC participants across different States would not notice any difference in reporting mileage, submitting payments, and accessing customer services. While this approach of interoperability would require a high degree of coordination and standardization of on-road technologies and back-office operations, it may be a desirable option for the Eastern States since they are closer to each other in proximity and intestate travel is more common. For instance, about 10% of all 1.4 million miles traveled during the RUC pilot project was outside of Delaware, New Jersey, North Carolina, and Pennsylvania, which highlighted the importance of adopting interoperability hubs in order to capture these transactions (2022).

Another dimension of interoperability is the ability to transfer data and settle transactions among agencies. Besides Hawaii, which is an island State with an existing annual vehicle inspection program currently administered by the Department of Transportation, other States would require data-sharing among governmental agencies or among governmental agencies and account managers. In most of the evaluated RUC programs, the data is collected and managed by account managers. If a RUC project has multiple account managers, like the case in

California, then there needs to be a central repository to accept the data collected from all account managers. This database infrastructure can serve as the backbone for building an interoperability hub, where mileage data collected from each State can be uploaded to a secure data repository, and any interstate travel would be determined and accounted for before invoicing the drivers through the system of their home State. Building a flexible and secure data repository would allow States to reduce administrative costs, which would increase the overall cost-efficiency of RUC programs.

Discussion

From the interviews and MCDA, we observed that there are many parallels between the transition to all-electronic and open-road tolling and the transition from motor fuel tax to RUC. While as an industry, tolling agencies share some common practices and standards, different agencies have tailored their technology and operation to meet the needs of their users. This is also reflected in the state-level RUC programs piloted to date, where each state has tailored their RUC programs to best serve its transportation funding needs. Despite the geographical differences, the key to designing a successful RUC is to have clear objectives and mechanisms for achieving these objectives, while allowing for enough flexibility to handle differences among participants. These differences can be participants' sociodemographic, geographies, and vehicle fuel efficiencies, which have implications on the financial impacts of RUC. In addition, the administration of RUC needs to ensure that unbanked and underbanked populations are not excluded. The tolling industry has successfully implemented other ways besides credit cards for unbanked and underbanked populations to pay their tolls. Tolling agencies have not had to grapple too much with the equity issue of devising different toll rates for populations of different income levels. This is in part due to populations can find alternatives to not accessing tolled roads. However, in the context of RUC, where all roads are priced, the alternative to not using them is not readily available or may largely impact mobility. Prioritizing equity considerations along all these dimensions would ensure that mitigations for these impacts are in place when RUC is being implemented at-scale.

Another key takeaway from our research is managing revenue leakage in the transition from a "pay now" to a "pay later" model when moving from gasoline tax to RUC. This transition is currently taking place in the tolling industry for its moving to an open-road and all-electronic system. The potential revenue leakage of a "pay later" model may largely compromise the efficiency gains from a more technology-centric and less manual system if safeguards are not implemented to reduce the incentives and means for toll or RUC evasions. Some potential safeguards mentioned in the interviews include partnering with the DMV to streamline the process of data request and account matching, so the accuracy of transactions matching to accounts increases. Another area of exploration is leveraging in-vehicle telematics to directly communicate with existing tolling technology in terms of mileage tracking. RUC implementation can also leverage such an opportunity to reduce the manual labor required in tabulating vehicles miles traveled while reducing chances of evasion or alteration. Lastly, there is a large potential to consolidate back-office account management between RUC and tolling. Instead of creating a brand-new customer service center that assists users with payments and processes transactions for billing, RUC implementation should consider leveraging the existing staffing and system infrastructures of the tolling industry. Furthermore, distance-based tolling such as express lanes already has the capability to track in-lane miles driven by vehicles, so there exists an additional opportunity to leverage existing tolling technology to track vehicles miles driven.

Conclusion

To pursue a sustainable and fair transportation funding system, many states have explored replacing the existing motor fuel tax with a usage-based per-mile charge. While there are uncertainties around implementing a new transportation revenue-generating policy, there are existing vehicle-level and usage-based pricing schemes, namely tolling. From interviewing tolling industry experts across the country and synthesizing lessons learned from their industry, we addressed the research question of how well-prepared each state is at integrating their RUC system with tolling. Furthermore, we also provided insights on the mutual benefits that can be accomplished under a RUC-tolling integration. Working collaboratively with each other, both the tolling industry and RUC programs can benefit from the increased scale of operations and the spur of technical innovations, especially on the in-vehicle telematics front, which would largely reduce administrative costs. In addition to the improved technical capabilities, it is also important to strengthen relationships among transportation agencies, namely the DMV, the tolling administrators, and the RUC implementation programs to ensure smooth data-sharing, transaction settlements, and enforcements of toll/ RUC payments. The increase in administrative capacity is as crucial as the innovation in technologies. Lastly, an area that is highly relevant in rate design and administration of RUC is ensuring equity in terms of alleviating financial burdens on low-income populations and ensuring that unbanked and underbanked populations have the means to pay for their RUC. Timely research on equity in rate-design is invaluable and essential in a successful RUC implementation.

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Data Management Plan

Products of Research

Interview data was collected in the form of audio recordings and stored according to the agreement with the UC Davis Institutional Review Board. The audio recordings are managed by the PI. The transcribed interviews and the analysis are managed by the PI, co-PI, and the graduate student.

Data Format and Content

There are audio recordings and paper documentation with the transcribed interviews. The transcribed interviews are anonymized. The literature review is maintained in an excel sheet with all the relevant information: title, author, journal/publisher of report, year, scope of research, and the main findings.

Data Access and Sharing

The Excel sheet with the literature review is available on the Dryad data repository at https://doi.org/10.25338/B8ZS9H. The Excel file summarizes the findings from the Road User Charge Pilot programs evaluated for this study and five other Department of Transportation reports.

Reuse and Redistribution

The interviews cannot be shared. The interviews have been summarized in the final report. The authors can only share the interview data and the transcriptions upon request. Please contact the PI for the interview data: Dr. Debapriya Chakraborty, dchakraborty@ucdavis.edu.

The literature review data should be cited as follows:

> Chakraborty, Debapriya; Jenn, Alan (2023), Tolling lessons learned for road usage charge, Dryad, Dataset, https://doi.org/10.25338/B8ZS9H