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The Present and Future of Road Financing: Leveraging knowledge from the tolling industry to implement road-usage charge programs in the U.S.

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Abstract

Historically, transportation funding in the United States has been supported primarily by motor fuel taxes. In recent years, revenues from fuel taxes have been shrinking. In response to the revenue shortfalls, many states have launched pilots or full-scale programs of road-usage charge (RUC) as an alternative to motor fuel taxes for transportation funding. Some of the challenges facing RUC is the cost of implementation compared to traditional motor fuel taxes, operational complexities, and the equity concerns (Caltrans, 2017). To address these challenges, states are looking to leverage existing vehicle-level pricing programs, such as road tolling, to learn about synergies between RUC and tolling. In this paper, we conducted semi-structured interviews with experts from tolling programs across the U.S. to identify areas of overlap between tolling and RUC. We built upon the interview findings by conducting a multi-criteria decision analysis (MCDA) to evaluate how well the state-level RUC pilots and programs can integrate with tolling systems. Our results demonstrate that there are numerous mutual benefits of a RUC-tolling integration. Both the tolling industry and RUC implementations can benefit from the increased scale of operations and the spur of technical innovations, which would reduce administrative costs. RUC programs can also learn from the tolling industry to address data privacy and security issues. In terms of policy and program designs of RUC, it is essential to design RUC rates which are equitable by considering the financial burdens on low-income populations and ensuring access to the system for the unbanked and underbanked populations.

1. Introduction

Transportation funding in the United States has historically been supported by motor fuel taxes, which are per-gallon taxes levied on gasoline and diesel for the purpose of funding the construction and maintenance of transportation infrastructure. In 2021, the federal motor fuel taxes raised about $32.8 billion in revenues which accounted for about 70% of the Federal Highway Trust Fund's expenditures on infrastructures (FHWA, 2022). However, with the increasing uptake of alternative fuels vehicles, improved vehicles fuel efficiencies, and inflation, the revenues generated by the motor fuel taxes are projected to dwindle, creating shortfalls in the federal infrastructure funding (Jenn, 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. In 2017, California passed the Road Repair and Accountability Act (Senate Bill 1) that increased the tax rates on gasoline and diesel. The Bill also introduced an annual registration fee of $108 on zero-emission vehicles to compensate for the fact that these vehicles do not contribute to road infrastructure funding via motor fuel taxes (Caltrans, 2022). 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 since it is not linked to the amount of driving by the vehicles. Furthermore, a yearly fee of $108 generates lower revenue compared to the average amount collected from fuel taxes per vehicle in California, which is approximately $260, assuming an average fuel efficiency of 25 MPG and an annual mileage of 12,000 miles. (Caltrans, 2017).

As a result, multiple states have begun exploring and, in some cases, even implementing a road-usage charge (RUC), also known as mileage-based user fee. Rather than being linked to fuel consumption, these programs 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, including California, Washington, Hawaii, and the Eastern Transportation Coalition (i.e., Delaware, New Jersey, North Carolina, and Pennsylvania) (National Conference of State Legislatures, 2022). Most recently, California is set to begin its second RUC pilot in June 2024, with the goal of testing multiple mileage collection options (State of California, 2024). Oregon, Utah, and Virginia launched full-fledged RUC programs where drivers can voluntarily opt-in to pay a RUC instead of motor fuel taxes. In 2022 alone, Hawaii, Massachusetts, Minnesota, Tennessee, Utah, Vermont, Virginia, and Washington considered legislations to set up or to expand existing RUC programs. For example, Hawaii enacted Senate Bill 3183 in January 2024 to transition all vehicles in the State to the RUC program by 2033 (State Senate of Hawaii, 2024). Meanwhile, legislators from Massachusetts, Vermont, and Tennessee are considering legislatures to conduct RUC pilot programs (National Conference of State Legislatures, 2022). Additionally, the federal Inflation Investment and Jobs Act, passed at the end of 2021, directed the U.S. Department of Transportation to begin establishing a national RUC pilot. Evidently, there is substantial momentum at both the state and federal levels to replace the motor fuel taxes with a RUC system, especially as the adoption of EVs continues to grow.

One of the fundamental challenges of a RUC program is the relatively prohibitive cost of implementation compared to traditional motor fuel taxes – higher administrative and enforcement costs (Caltrans, 2017). The administration of the motor fuel taxes, less than 1% of the collected revenue, benefits from the fact that fees are collected from a small number of bulk storage terminals, which amounts to slightly more than a thousand across the entire country. Meanwhile, 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. One strategy to address issues related to high administrative costs and other implementation challenges of a RUC program is to leverage existing vehicle-level pricing programs, such as road tolling systems to gain knowledge from their implementation challenges and to learn of synergies between the programs.

In this paper, we looked specifically at road-tolling programs in the U.S., synthesizing the lessons learned from the implementation of these systems and devising potential opportunities within these programs to collaborate with a RUC program. To elicit insights from the tolling industry, we conducted nine semi-structured interviews with experts from tolling programs across the country. Following the interviews, we identified key themes related to program administration, operational challenges, data privacy, and equity concerns which are relevant to both tolling and RUC programs. We then built upon these key themes with findings from state-level RUC reports by conducting a multi-criteria decision analysis (MCDA) to evaluate how well the state-level RUC pilot projects can integrate with tolling systems. Synthesizing the insights gained from the expert interviews to inform the objectives and evaluation criteria in the MCDA, we leveraged a two-pronged approach to provide policy guidance for large-scale implementations of RUC.

2. Background and Literature Review

Historically, the Federal Highway Act of 1921 provided federal financial assistance to states for building highways to improve nationwide connectivity to accommodate the rise of automobile usage

(Kirk, 2019). Tolls were collected on many of these roads, bridges, and tunnels to help pay for their construction and maintenance. However, 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 motor fuel taxes revenues, which continued for a few decades (Kirk, 2017). 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 prompted the revival of the need for tolling (Kirk, 2017). 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.

In addition to being a revenue-generating source for transportation infrastructure funding in the U.S., tolling, when linked with time- and usage-based road pricing, can address negative externalities associated with transportation. Economists have long advocated for pricing the use of roadways as an efficient way of allocating scarce roadway capacity and tackling the negative externalities, including congestion, air and noise pollution, and road wear-and-tear (Vickrey, 1965). Examples of road pricing include distance-based tolling, cordon tolling, congestion pricing, and RUC. Until very recently, road pricing has rarely been implemented in the United States and is strongly opposed by the public and elected officials due to the nature of charging drivers a fee in addition to paying motor fuel taxes, resistance to paying more for transportation, and privacy concerns, among other things (Schade & Schlag, 2003). While road-pricing has faced public resistance in the United States, it has been implemented in other countries to externalities, such as air pollution, congestion, and noise pollution. 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 & Carslaw, 2005, Börjesson & Kristoffersson, 2018, Lehe, 2019). Some of the major motivations behind these road pricing schemes included the reduction of greenhouse gases (GHG) and local air pollutants as well as congestion mitigation (Beevers & Carslaw, 2005, Deng, 2017). Beevers & Carslaw found that the London congestion charging scheme, which went into effect in 2003, has reduced particulate matter 10 (PM10) emissions by 12% in the charging zone (2005).

Motivated by the potential societal benefits realized by road pricing schemes, researchers have conducted both quantitative and qualitative analysis on them. Some examples of quantitative analysis include cost-benefit analysis conducted by Anas and West & Börjesson to evaluate the benefits of congestion pricing in the Greater Los Angeles region and Gothenburg, respectively (2020, 2020). They both found congestion pricing schemes to be socially beneficial, effective at reducing congestion, and generate positive revenues that can be recycled to the public. Similarly, Casady et al. applied a benefit-cost analysis to investigate toll managed lanes on seven projects in the U.S. and found that two out of seven projects yield positive benefits (2020). Odeck and Eliasson & Mattson employed regression-based analysis to estimate operational costs of tolling systems and the distributional impacts of congestion pricing, respectively (2019, 2006). They found that the increasing volume of vehicles using the tolling facility reduces operational costs, demonstrating the existence of economies of scale.

Meanwhile, a plethora of qualitative analysis has been conducted, such as public acceptance study (Agrawal et al., 2016, Rentziou et al., 2011, Zmud et al., 2008), acceptance by elected officials (Hensher & Bliemer, 2014), equity impacts analysis (Hosford et al., 2021), and the interactions between land use policies and road pricing (Guo et al., 2011). The studies found several factors are important when considering road-pricing schemes to fund transportation infrastructure, including concerns about privacy

and data security, the administrative burdens, and the equity implications of the redistribution of congestion pricing revenues. While existing literature revealed some of the salient concerns about road pricing, these studies considered standalone cordon tolling or congestion tolling projects. Moreover, these studies focused on the impacts of road pricing programs on addressing environmental pollution, congestion, and equity concerns, and not on the administrative, technical, or operational challenges of implementing these systems.

Since one of the fundamental challenges of a RUC program is the relatively excessive cost of implementation compared to traditional motor fuel taxes, some state agencies and metropolitan planning organizations (MPOs) have conducted pilot studies to explore these challenges. In the wave of states testing and adopting RUC programs, it is important to thoroughly investigate the overlaps between existing tolling systems and RUC to understand the impacts that these programs can have on each other. To accomplish this goal, we focused on detailing the lessons learned from the semi-structured interviews to gather information about key topics in RUC-tolling integration. These topics include technology, operations, administration, and equity implications. The paper proceeds as follows: Section 3 covers the methodology on qualitative semi-structured interviews and MCDA. Section 4 presents the results from interview analysis and the MCDA. Section 5 discusses the results and highlights important findings, and Section 6 concludes.

3. Methodology

We used a two-pronged analysis approach, where we began with conducting semi-structured interviews and identifying themes from our interviews. The second piece of our analysis leveraged the thematic findings from the interviews to inform the evaluation criteria for the MCDA. This approach allowed us to integrate the learnings from our expert interviews with findings from state-level RUC programs, which led us to craft well-informed and timely policy recommendations to RUC program practitioners.

3.1. Interview Approach

Over the period of July to October 2022, our team conducted nine semi-structured interviews with tolling industry experts across the United States. 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 & 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 (2017). Therefore, we elected to conduct semi-structured interviews to gain in-depth knowledge from our experts. To conduct the interviews, we first designed a set of questions which was informed by our literature review on road pricing programs. The topics covered in the questions included system operations, finances, data collection and handling, and technology.

Our recruitment strategy of interviewees 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 ten years of experience working in the industry, and they represent a body of knowledge that spans across the tolling industry, including

development/deployment, technology, pricing and payment, policy, and administration. The interviewees were contacted via email, inviting them to a 45 to 60-minute interview. Most of the interviewed experts have worked in states that have implemented RUC programs or conducted RUC demonstrations, which makes them the ideal candidates for eliciting opinions on RUC-tolling integration. We also heard from experts who operate tolling systems in states that have not yet 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 the interview as well. Table 1 below summarizes the interviewees' organization, organization type, whether they are from the private or public sector, the geographic area of representation, and the date of the interview.

The interviews were conducted by a pair of researchers. 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 a 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 Section 4.

Table 1. Organizations represented by the interviewed tolling industry experts.

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

North Texas Tollway Authority (NTTA)	Tolling agency	Private	Dallas-Fort Worth Area, TX	October 28, 2022

3.2 Multi-criteria Decision Analysis

MCDA is an evaluation technique from the discipline of operations research, and it has been developed for the past four decades with the goal of evaluating decisions that include multiple and often conflicting criteria (Stein, 2013). Criteria may include financial, technical, and social factors that influence the decision-making process. Evaluations of these criteria may be based on historical data or preference rankings by experts (Stein, 2013). Because of its ability to accommodate multiple criteria in its evaluation, 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 decisionmakers establish preferences among different alternatives (Multi-Criteria Analysis, 2009). The process for designing a MCDA is as follows identifying the objectives, identifying options for achieving the objectives, identifying criteria that can be evaluated to compare the options, analyzing the criteria in the context of evaluating the options, and arriving at a decision (Multi-Criteria Analysis, 2009). MCDA helps decisionmakers recognize the trade-offs among the alternatives; a crucial step in the exploratory stage of implementing RUC programs and tolling-RUC integration when policymakers from different states may learn from each other and tailor RUC implementations to fit their state's transportation funding needs.

To operationalize a MCDA in the context of RUC-tolling integration, we identified the objective as evaluating how well the state-level RUC pilot projects conducted to date can integrate with tolling systems. Then to identify the options for achieving the objective, we reviewed reports 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. These objectives are revenue generation, equity, technology feasibility, public acceptance, and autonomy. After identifying the objectives of state-level RUC programs, 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 state-level RUC reports. 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, which are affordability and inclusiveness/accessibility. To translate these findings to evaluation criteria for RUC, we measured how affordable a RUC program is and how accessible and inclusive it is. For instance, we scored "5" on "accessibility/inclusiveness", if the program is open to all drivers with additional mechanisms to improve accessibility for populations with different needs (e.g., technology barrier, language barrier). A score of "3" or below on accessibility/inclusiveness indicated that the RUC program is only open to selected drivers.

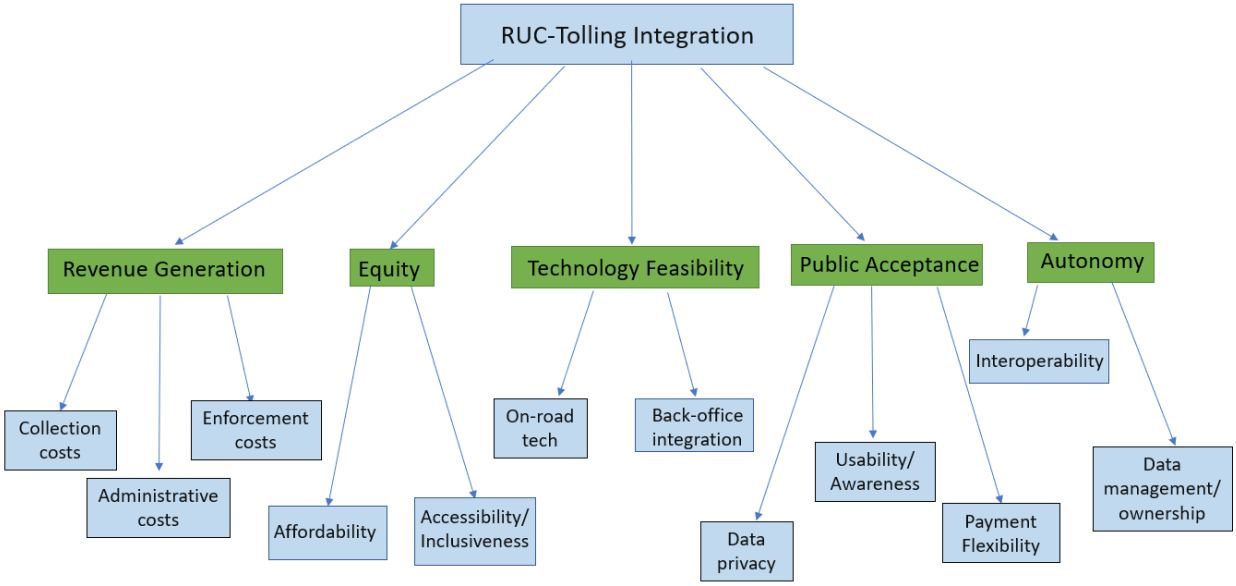

Figure 1. Value tree in the RUC-tolling integration context emphasizes the objectives that the integration is trying to achieve, including revenue generation, equity, technology feasibility, public acceptance, and autonomy.

In evaluating a complex decision that involves multiple objectives, 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 reports for each of the abovementioned states and organized them in a performance matrix. The main purpose of a performance matrix is to present each alternative against the evaluation criteria to describe each alternative's performance on the criteria. For this project, the evaluated alternatives are the states that have conducted a RUC pilot or have an operational RUC program, including California, Colorado, Eastern Transportation Coalition, Hawaii, Minnesota, Oregon, Utah, and Washington. Our interviewed experts have experience working on tolling in California, North Carolina, Oregon, and Utah, representing about 40% of the states evaluated in the MCDA. 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. Table 2 below presents the rubric of our evaluation which provides additional details on the ratings.

Table 2. Evaluation Rubric for each Criterion

	Evaluation Rubric					
Criteria	n/a	1	2	3	4	5
Collection costs	No mentioning of collection costs	Some mentions 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

	Evaluation Rubric					
Criteria	n/a	1	2	3	4	5
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
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 one mileage reporting option only	Focused on one mileage reporting options with the goal of expanding	Focused on three to four mileage reporting options	Offered a variety of mileage reporting options, including manual and automated options
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	Leveraged account manager to provide data collection, processing, and

	Evaluation Rubric					
Criteria	n/a	1	2	3	4	5
					invoices.	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 personally identifiable information (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
Interoperability	No mentioning of interoperability	Vague mention of interoperability	Interoperability was not assessed	Interoperability was not assessed but indicated as a future research area	Assessed interoperability with other states	Assessed 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

4. **Results**

The results of the MCDA present the evaluations of existing RUC programs and pilots based on the key characteristics synthesized from our expert interviews and evaluation criteria identified in Figure 1. Table 3 provides the evaluation of eight RUC programs with '5' indicating that the state 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 3. 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 Cost	Administrative Costs	Enforcement Costs	Affordability	Accessibility / Inclusiveness	On-road Tech	Back-office integration	Data Privacy	Usability/ Awareness	Payment Flexibility	Interoperability	Data management/ Ownership
CA	3	5	4	3	3	5	4	5	5	3	4	4
CO	3	3	4	3	4	4	5	4	5	3	3	3
TETC*	4	4	4	5	4	4	5	4	5	2	5	5
HI	4	4	3	4	4	5	4	5	5	3	2	2
MN	3	3	3	3	2	3	5	4	4	2	4	3
OR	3	4	4	4	4	3	5	4	4	3	4	4
UT	4	4	4	4	3	4	4	5	5	4	3	4
WA	4	5	4	3	4	5	5	4	4	3	4	5

*The Eastern Transportation Coalition

A. Revenue Generation

To assess 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 state-level RUC reports either provide quantitative estimates on costs or qualitative descriptions on how to reduce these costs. In terms of administrative costs, all the states agree that administrative costs of RUC would be much greater than those 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 taxes, which is about 0.5% of revenues, the administrative costs of RUC range from 7% to 12%. For instance, Washington estimated that the administrative costs of a RUC are about 7% and 12% for the manual odometer reporting option and the electronic odometer reading device, respectively (2020). 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 from a small percentage of the state's driving population. As RUC programs transition to replace motor fuel taxes for all drivers, the administrative costs would decrease to the lower end of approximately 5% of total revenue.

Given the limitation of data availability around cost estimates, our interview findings shed light on some aspects of the potential revenue-generating capacity of a RUC-tolling integration by drawing on

lessons learned from the tolling industry. When moving to an open-road and all-electronic tolling system, where vehicles do not need to stop to pay tolls, agencies are concerned about leakage in toll collections. One 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. One of the interviewed experts expressed that even though tolling agencies can work with the Department of Motor Vehicles (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. The remaining 6% of leakage is associated with unidentifiable vehicles, which can take the form of vehicle owners intentionally disguising their license plates. In total, both forms of leakage account for approximately 14% of total transactions on the NTTA tolling system, which amounts to a loss of revenue n the order of millions of dollars annually.

To mitigate the impact of revenue leakage, the interviewed experts encourage their users to adopt radio frequency identification (RFID) transponders, because these established accounts are usually backed by credit cards. According to the interviewees, the leakage rate of RFID transponder transactions is less than 1%. In applying this insight to RUC implementations, the interviewed tolling experts recommend a "pay now" model, where users are charged a certain amount of money based on their expected usage of the road. A true-up is conducted on a monthly, quarterly, or annual basis to ensure that users are being fairly charged for their use of the roads, and that the charge would not create an undue financial burden for them. Considering these lessons learned from tolling systems about revenue leakage, most state-level RUC pilots and programs have proposed several solutions which are tailored to the state's existing programs. For instance, Hawaii conducts inspections of vehicles as part of their annual registration (2022). 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 (2017). On the other hand, Minnesota has approached this issue differently by leveraging in-vehicle telematics to directly capture and report mileage driven by vehicles to RUC agencies (2022). The integration between tolling and in-vehicle telematics is also an area of interest that many states would like to explore. Collaboration with automakers on this front could potentially reduce the cost barrier to accessing these data and help build a secure system for auto manufacturers to share these data with tolling and RUC agencies. Lastly, given the characteristics and existing infrastructures, each state should have the autonomy to design and to implement a RUC program that not only minimizes costs but also works well for their residents.

B. Equity

The equity considerations from each state's RUC program are evaluated by the affordability and the 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 brought up by many of the RUC reports is whether the implementation of RUC would disproportionately and negatively impact rural drivers who tend to travel longer distances to access required services. This concern is addressed by many states' RUC programs via recruiting participants from a wide range of geographies and evaluating the difference between their RUC payments and their motor fuel tax payments. For instance, the 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 a RUC because they tend to drive less fuel-efficient vehicles which amounts to higher motor fuel tax payments. The estimated difference in annual payment between a RUC and a gasoline tax is about $18 for rural drivers (2022).

Another area of equity consideration is considering the affordability of RUC for different segments of the driving population, especially in the context of RUC where alternatives to not using the roads may not exist for some populations or would significantly reduce their mobility and quality of life. For instance, as mentioned by one of the interviewees, 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. According to the interviews, one potential solution to this is to implement a flexible payment frequency as part of RUC enrollment, so drivers can decide whether a monthly, quarterly, or biannually payment frequency would reduce their financial burden.

Researchers have also investigated the adoption of an income-based RUC rate, where lower-income drivers would pay a lower per-mile fee than higher-income drivers. This may help address the regressivity of RUC by lowering the financial burden on lower-income drivers (Speroni et al., 2022). Thus far, the conversations around the rate-setting of RUC have been centered on ensuring fairness and equality, as demonstrated by states like Utah and Hawaii waiving the enhanced registration fee on EVs and devising a cap of RUC at the average annual gasoline tax payment, respectively (2021, 2022). 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 taxes to RUC. While these considerations are important for designing a fair transportation funding mechanism, they do not address the disproportional impacts that RUC may pose on drivers of different income levels. These equity challenges need to be addressed via careful rate-setting to minimize the regressivity of RUC.

Another aspect of equity that interviewees mentioned 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. Furthermore, NTTA partners with a cell phone carrier to allow the transfer of tolls to users' monthly phone bills. 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 payment method is important to the implementation of RUC.

C. Technology Feasibility: on-road technology

To evaluate how feasible the technology integration is between RUC and tolling, we focus on two areas: the on-road technology and the back-office integration. All the states, except for Minnesota, offer multiple mileage-reporting options to their RUC participants, including GPS-enabled onboard diagnostic devices (OBD), non-GPS-enabled OBD, smartphone-based apps, manual odometer image captures, and in-vehicle telematics. An OBD is a plug-in device which allows drivers to view diagnostic data regarding their vehicle, such as the powertrain, emission control systems, and speed. GPS-enabled OBD allows vehicles to be tracked in real-time in terms of their location. Smartphone-based apps leverage GPS technology to track the location and miles driven by vehicles. Manual odometer image capture involves the drivers taking a picture of their odometer and submitting it. Offering a plethora of technological options not only allows the states and the account managers to evaluate different on-road technologies, but it 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.

California and Washington offered the most 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 choose 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 (2020). 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 (2022). This difference in preferences for on-road technology emphasizes the geographical differences and the need to tailor RUC program designs to each state's residents and its existing processes to bring the most familiarity to both the RUC participants 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's on-road technology is to distinguish whether the miles were driven inside or outside of 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 (2017, 2021). 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 by leveraging the RFID technology. All the tolling agencies that we interviewed are moving towards an open-road tolling system with all-electronic tolling technologies because of the increase in efficiency and accuracy of toll collections. To do so, they rely on all-electronic tolling technologies, which include RFID-reading technology, 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 in the vehicle. As an application to RUC, the Eastern Transportation Coalition conducted a tolling-RUC integration pilot on passenger vehicles in 2021 by recruiting about two hundred 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 eight feet from other traffic flows or toll plazas and cumulative tolls collected as vehicle passes under gantry. This result demonstrates that it is technologically feasible to integrate RUC and tolling using existing the 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 (2022). The in-vehicle telematics on heavy-duty trucks require professional installation which prevents any potential odometer fraud and provides accurate mileage data. Vehicles' miles driven on tolling systems are 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 do not have RFID-transmitting technology, then additional technology solutions would need to be implemented to capture these miles for RUC, such as camera captures of license plates. Furthermore, there currently exists a barrier for tolling agencies to leverage in-vehicle telematics because they are proprietary to the auto manufacturers. Future directions on tolling-RUC integration should consider leveraging both in-vehicle telematics and GPS-enabled OBD to evaluate more complex tolling configurations and business rules and to reduce technology redundancy.

D. Technology Feasibility: back-office integration

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. 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 DMV to identify the vehicle owners. From our interview with the Ohio Turnpike and the NTTA, their annual operational costs of the back-office are about $3 and $35 million dollars, respectively. The operational costs of the Ohio Turnpike back-office included staff salaries, which comprised of approximately 50% of the costs. Software systems maintenance consisted of approximately 34% of the annual operational costs of the Ohio Turnpike. Given that the Ohio Turnpike manages approximately 440,000 accounts, this translates to approximately $6.8 per active account of annual operating costs. As the scale of the tolling system increases, the per-account operational cost decreases. The NTTA manages 11 million active accounts, which yields a per-account operational costs of $3.2. Because of the similarities in the requirements and capabilities of a tolling system's back-office and those of the RUC program, the Eastern Transportation Coalition, Oregon, and Washington have expressed interest in integrating the back-office operations between tolling and RUC. Like the tolling agencies, the RUC program's back-offices are operated by third-party account managers who interface with the RUC participants to collect their data, to process their transactions and invoices, and to answer any customer service-related questions.

An essential component of back-office integration in RUC, whether it is with tolling agencies or with other governmental agencies, is creating technical infrastructures for data-sharing. With the implementation of RUC, the interviewed experts agree that there exists an opportunity to ensure that business rules and processes are in place for the 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 the cost-efficiency and security of the program. For instance, 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.

E. 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 is emphasized by tolling agencies, especially in providing a 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, states have mostly addressed payment flexibility around the payment frequency. For instance, Hawaii found that about 52% of their 39,600 surveyed 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 to reduce administrative costs associated with more frequent payments (2021). On the front of payment methods, California, Colorado, Minnesota, and Utah assessed 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 ontwo 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 about 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 tates need to enact and enforce the most stringent data privacy laws for the RUC program. Learning from the tolling industry, the back office of the tolling agencies is PCI-compliant which means that they adhere to the Payment Card Industry (PCI) Data Security Standards regarding 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, which prevents sensitive PII from being transmitted in its original format. According to the interviewed experts, tolling agencies are required by state laws, such as the case in California, to purge the data within 30 days when it is no longer needed. When applying to RUC implementation, 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 will provide the necessary peace-of-mind to RUC participants.

On the usability and awareness front, we evaluate the efforts that the states have taken to educate the public about RUC via surveys and focus groups. In addition to conducting RUC pilots, public education and outreach about RUC is essential to promoting the public's acceptance of this new transportation funding mechanism. Through an extensive outreach program, Hawaii surveyed about 40,000 residents. 80% of the surveyed residents indicated that they are aware of state and county gas taxes as a means for funding transportation infrastructure (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 (2017). 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 the states further highlight the importance of education and outreach efforts on RUC. Except for Hawaii, the residents from other states were not familiar with RUC or motor fuel taxes as a means to fund transportation infrastructure. Despite that, most of the RUC pilot participants became supportive of replacing the motor fuel taxes with RUC. 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 to educate the public on transportation infrastructure funding.

F. Autonomy

As demonstrated in the evaluations of the above criteria, geographical differences largely influence how states may approach RUC implementation. Through conducting pilot projects, each state learns about the technology options, the reporting options, and the administration of RUC which are best suited for their residents. Recognizing that RUC implementation would not be "one-size-fits-all" and that states should have the autonomy to design and to implement their RUC program, we evaluate 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 to allow RUC implementation and enforcement. Drawing from lessons learned from tolling agencies, we define interoperability in the context of RUC implementation as the ability for multiple RUC programs to exchange data on transactions and on vehicles to accurately collect 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 (2021, 2020). Under this model, each state has 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 evaluated between two pairs of Western States: Oregon-Washington and California-Oregon by leveraging GPS-enabled OBD. The drivers only got billed by their home state agency, which reduced the burden on drivers to pay multiple agencies. While the technologies of interoperability hubs are feasible, one of the challenges that Washington expressed is the administrative burden in determining the amount and the location of fuel that each vehicle purchased to process refunds of motor fuel taxes paid (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). The efunds for motor fuel taxes paid would occur during the transitional period from motor fuel taxes to RUC, especially those who voluntarily opt into the RUC program. As RUC implementation becomes more widespread, processing refunds will be less administratively burdensome.

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 service. While this approach of interoperability requires 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 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 Hawaii 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 program has multiple account managers, like in the case of California, then there needs to be a central repository to accept the data collected from all the account managers (2017). This database infrastructure serves as the backbone for building an interoperability hub, where mileage data collected from each state is 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. Many interviewed experts expressed that there exists an opportunity to leverage the existing account management and customer service expertise from tolling agencies to manage the administration and collection of RUC payments. For instance, the account holders in the NTTA tolling system cover 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 should be leveraged by RUC implementation to consolidate the back-office operations to reduce administrative costs.

5. 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 taxes 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, where each state has tailored their program 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 manage differences among participants. These differences can be participants' sociodemographic characteristics, 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 alternative 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 due to the fact that populations can find alternatives to not access 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 greatly impact mobility. Prioritizing equity considerations along all this dimension 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 motor fuel taxes to RUC. This transition is currently

taking place in the tolling industry for its move 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 to track mileage. 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, 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.

5.1 Policy Recommendations

Based on the above discussion of findings from our MCDA and semi-structured interviews, we provide the following policy recommendations for stakeholders associated with implementing a RUC program.

Table 4. Summary of policy recommendations for the relevant stakeholders: state agencies, auto manufacturers, and third-party account managers.

Stakeholders	Objective	Recommendations
State agencies	Revenue generation	1) Create a payment system where RUC participants pay a certain amount at the beginning of the payment period to avoid revenue shortfalls. True-ups can happen on a quarterly or annual basis.
	Equity	2) Implement a flexible payment frequency, so RUC participants can decide whether a monthly, quarterly, or biannual payment is appropriate for their financial situation.
		3) Offer multiple RUC payment options to reduce the technology burden on unbanked or underbanked populations.
	Technology: on-road	4) Explore both in-vehicle telematics and GPS-enabled OBD to evaluate feasibility of capturing transactions.
	Technology: back-office	5) Cohesive integration between the state's Department of Motor Vehicles to obtain vehicle data efficiently
	Public acceptance	6) Statutory protection of personally identifiable information
Auto manufacturers	Technology: on-road	7) Reduce cost barriers for accessing in-vehicle telematics data for mileage reporting

Third-party account managers	Technology: back-office	8) Build a flexible and secure database to exchange and to transfer pertinent information among the implementing agencies and customers
	Public acceptance	9) Ensure the highest standards of data management and security
	Autonomy	10) Leverage the existing account management and customer service expertise from tolling agencies to manage the administration and collection of RUC payments

6. Conclusion

To pursue a sustainable and fair transportation funding system, many states have explored replacing the existing motor fuel taxes with a usage-based per-mile charge. While there are uncertainties around implementing a new transportation revenue-generating policy, there are lessons learned from tolling which can mutually benefit both RUC and 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 and 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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REFERENCES

Agrawal, A. W., Nixon, H., Hooper, A. M., National Cooperative Highway Research Program, National Cooperative Highway Research Program Synthesis Program, Transportation Research Board, & National Academies of Sciences, Engineering, and Medicine. (2016). Public Perception of Mileage-Based User Fees (p. 23401). Transportation Research Board. https://doi.org/10.17226/23401

Anas, A. (2020). The cost of congestion and the benefits of congestion pricing: A general equilibrium analysis. Transportation Research Part B: Methodological, 136, 110–137. https://doi.org/10.1016/j.trb.2020.03.003

Beevers, S., & Carslaw, D. (2005). The impact of congestion charging on vehicle emissions in London. Atmospheric Environment, 39(1), 1–5. https://doi.org/10.1016/j.atmosenv.2004.10.001

Börjesson, M., & Kristoffersson, I. (2018). The Swedish congestion charges: Ten years on. Transportation Research Part A: Policy and Practice, 107, 35–51. https://doi.org/10.1016/j.tra.2017.11.001

California Department of Motor Vehicles. (2023). Registration fees. https://www.dmv.ca.gov/portal/vehicle-registration/registration-fees/

California Department of Transportation. (2022). Caltrans Facts 2022. https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/caltrans-fact-booklets/2022-caltrans-factsv2-a11y.pdf

California Department of Transportation., California Transportation Commission., The Road Charge Technical Advisory Committee. (2017). California Road Charge Pilot Program. https://caroadcharge.com/media/htbpngos/rcpp-final-report-a11y.pdf

California Vehicle Codes of 2017. Stats. 1959, Ch. 3. https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml

Casady, C. B., Gómez-Ibáñez, J. A., & Schwimmer, E. (2020). Toll-managed lanes: A simplified benefit-cost analysis of seven US projects. Transport Policy, 89, 38–53. https://doi.org/10.1016/j.tranpol.2020.02.001

Colorado Department of Transportation. (2017). Colorado Road Usage Pilot Program Final Report. (CDOT-2017-11). Denver, CO.

Deng, X. (2017). Curbing Congestion and Vehicular Emissions in China: A Call for Economic Measures: Curbing Congestion and Emissions in China. Asia & the Pacific Policy Studies, 4(2), 354–361. https://doi.org/10.1002/app5.170

Eliasson, J., & Mattsson, L.-G. (2006). Equity effects of congestion pricing. Transportation Research Part A: Policy and Practice, 40(7), 602–620. https://doi.org/10.1016/j.tra.2005.11.002

Federal Highway Administration. U.S. Department of Transportation. (2021). Status of the Federal Highway Trust Fund (1) Fiscal Years 1957 - 2021. https://www.fhwa.dot.gov/policyinformation/statistics/2021/pdf/fe210.pdf

Federal Highway Administration. U.S. Department of Transportation. (2022). State & Urbanized Area Statistics - Annual VMT. https://www.fhwa.dot.gov/ohim/onh00/onh2p11.htm

Guo, Z., Agrawal, A. W., & Dill, J. (2011). Are Land Use Planning and Congestion Pricing Mutually Supportive?: Evidence from a Pilot Mileage Fee Program in Portland, OR. Journal of the American Planning Association, 77(3), 232–250. https://doi.org/10.1080/01944363.2011.592129

Hardman, S., Shiu, E., Steinberger-Wilckens, R., & Turrentine, T. (2017). Barriers to the adoption of fuel cell vehicles: A qualitative investigation into early adopters' attitudes. Transportation Research Part A: Policy and Practice, 5, 166–182. https://doi.org/10.1016/j.tra.2016.11.012

Hawaii Department of Transportation. (2022). Hawaii Road Usage Charge Demonstration Final Report. https://hiruc.org/hiruc-final-report-flipbook/

Hawaii State Senate. (2024). S.B. No. 3183. Relating to Road Usage Charge Program. https://www.capitol.hawaii.gov/sessions/session2024/bills/SB3183_SD1_.HTM

Hensher, D. A., & Bliemer, M. C. J. (2014). What type of road pricing scheme might appeal to politicians? Viewpoints on the challenge in gaining the citizen and public servant vote by staging reform. Transportation Research Part A: Policy and Practice, 61, 227–237. https://doi.org/10.1016/j.tra.2014.02.017

Hosford, K., Firth, C., Brauer, M., & Winters, M. (2021). The effects of road pricing on transportation and health equity: A scoping review. Transport Reviews, 41(6), 766–787. https://doi.org/10.1080/0141647.2021.1898488

Jenn, A. (2020). Federal Road Charge Tax Administration Process. https://doi.org/10.7922/G22805WD

Kirk, R. S. (2017). Tolling U.S. Highways and Bridges. Congressional Research Service.

Kirk, R. S. (2019). The Highway Funding Formula: History and Current Status. Congressional Research Service.

Lehe, L. (2019). Downtown congestion pricing in practice. Transportation Research Part C: Emerging Technologies, 100, 200–223. https://doi.org/10.1016/j.trc.2019.01.020

Minnesota Department of Transportation. (2022). Final Report: Minnesota Distance-based Fees Project. https://dbf.dot.state.mn.us/media/final_report_2022/Minnesota%20Distance-Based%20Fees%20Project%20Final%20Report%20August%202022.pdf

National Conference of State Legislatures. (2022). Road Usage Charge Fact Sheet: The Eastern Transportation Coalition. https://www.ncsl.org/transportation/state-road-usage-charge-toolkit/road-usage-charge-fact-sheet-the-eastern-transportation-coalition#:~:text=Additional%202021%20Legislation&text=Massachusetts%20(SB%202350%2C%20pending),not%20participated%20in%20the%20RUC.

National Conference of State Legislatures. (2022). State Road Usage Charge Series. https://www.ncsl.org/transportation/state-road-usage-charge-toolkit

New York Department of Transportation. (2024). Congestion pricing will unlock a better New York. https://congestionreliefzone.mta.info/

Odeck, J. (2019). Estimating and predicting the operational costs of road tolls: An econometric assessment using panel data. Transportation Research Part A: Policy and Practice, 130, 466–478. https://doi.org/10.1016/j.tra.2019.09.047

Rentziou, A., Milioti, C., Gkritza, K., & Karlaftis, M. G. (2011). Urban Road Pricing: Modeling Public Acceptance. Journal of Urban Planning and Development, 137(1), 56–64. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000041

Santos, G. (2005). Urban Congestion Charging: A Comparison between London and Singapore. Transport Reviews, 25(5), 511–534. https://doi.org/10.1080/01441640500064439

Schade, J., & Schlag, B. (2003). Acceptability of urban transport pricing strategies. Transportation Research Part F: Traffic Psychology and Behaviour, 6(1), 45–61. https://doi.org/10.1016/S1369-8478(02)00046-3

Speroni, S., Agrawal, A., Manville, M., & Taylor, B. D. (2022). Charing drivers by the gallon vs. the mile: an equity analysis by geography and income in California. Mineta Transportation Institute. https://transweb.sjsu.edu/sites/default/files/2238-Agrawal-Equity-Analysis-Road-User-Charge.pdf

State of California. (2024). California road charge. https://caroadcharge.com/

Stein, E. W. (2013). A comprehensive multi-criteria model to rank electric energy production technologies. Renewable and Sustainable Energy Reviews, 22, 640–654.

The Department of Communities and Local Government: London. (2009). Multi-criteria Analysis: a manual. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/7612/1132618.pdf

The Eastern Transportation Coalition. (2022). Exploration of Mileage-based User Fee Approaches for All Users. https://tetcoalitionmbuf.org/wp-content/uploads/2022/02/Exploration-of-Mileage-Based-User-Fee-Approaches-for-All-Users_Condensed-1.pdf

Oregon Department of Transportation. (2017). Oregon's Road Usage Charge Final Report. https://www.oregon.gov/odot/Programs/RUF/IP-Road%20Usage%20Evaluation%20Book%20WEB_4-26.pdf

Oregon Department of Transportation. (2021). Road User Fee Task Force Report to the Oregon Legislative Assembly. https://www.oregon.gov/odot/Programs/RUF/RUFTF_REPORT_2021.pdf

Utah Department of Transportation. (2021). Utah Road Usage Charge Report as required by Senate Bill 150. https://le.utah.gov/interim/2021/pdf/00002250.pdf

Vickrey, W. S. (1965). Pricing in Urban and Suburban Transport. The American Economic Review, 53(2), 452—465.

Washington Transportation Commission. (2020). Washington State Road Usage Charge Assessment Final Report. https://waroadusagecharge.org/wp-content/uploads/2020/01/WSTC-Final-Report-Vol-1-WEB-2020_01.pdfs

West, J., & Börjesson, M. (2020). The Gothenburg congestion charges: Cost–benefit analysis and distribution effects. Transportation, 47(1), 145–174. https://doi.org/10.1007/s11116-017-9853-4

Zeigler-Hill, V., & Shackelford, T. K. (Eds.). (2020). Encyclopedia of Personality and Individual Differences. Springer International Publishing. https://doi.org/10.1007/978-3-319-24612-3

Zmud, J. P., Arce, C., Transportation Research Board, National Cooperative Highway Research Program Synthesis Program, & Transportation Research Board. (2008). Compilation of Public Opinion Data on Tolls and Road Pricing (p. 14151). National Academies Press. https://doi.org/10.17226/14151