Improving Mobility for Suburban and Rural Communities Through Innovative Transit Approaches: A Comparative Cost Evaluation

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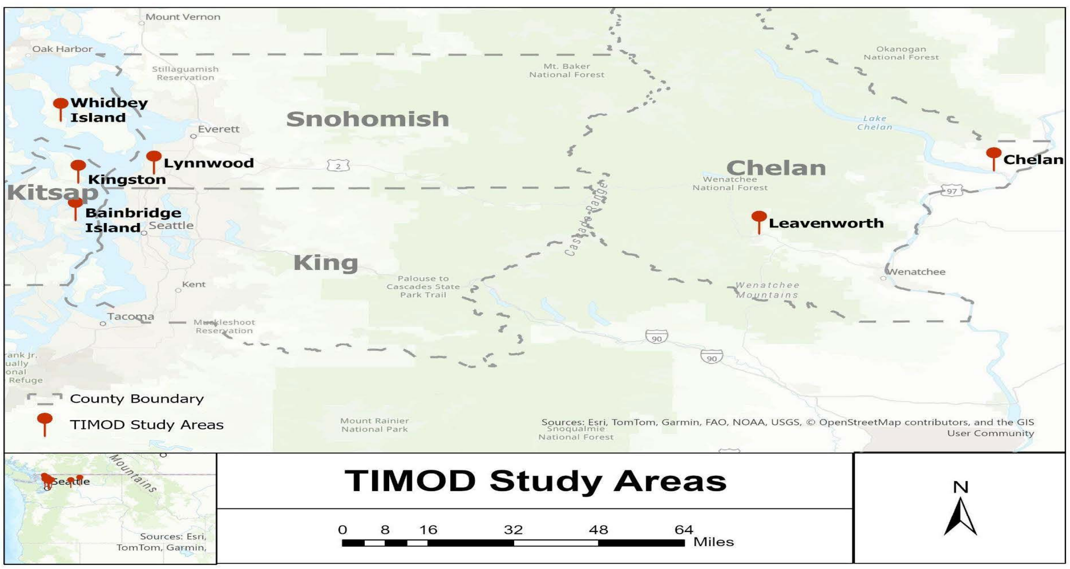

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IMPROVING MOBILITY FOR SUBURBAN AND RURAL COMMUNITIES THROUGH INNOVATIVE TRANSIT APPROACHES: A COMPARATIVE COST EVALUATION

by

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16. Abstract

Transit incorporating mobility-on-demand (TIMOD) represents the public-private partnerships in which transit agencies incorporate demand-responsive transportation services to supplement fixed-route transit. This study evaluated the cost-effectiveness of TIMOD in comparison to that of buses, driving, and ride-hailing in low-density suburban and rural settings. For each alternative, it estimated the costs for travelers, service providers, and transportation externalities, which constitute the social cost. In most of the study cases, TIMOD was the least cost-effective option, with the estimated social cost at least over two times higher than that of driving. For travelers, TIMOD can be the most cost-effective option in some cases when time value and trip fare are accounted for. Areas with lower transit service density benefit more from TIMOD, as it offers greater reductions in time costs than fixed-route transit. Transit agencies should explore alternative ways to improve mobility for residents in low-density areas, for example, by offsetting driving costs and subsidizing transportation network company (TNC) fares.

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Executive Summary

Problem Statement

This study pursues two objectives: 1) further developing a comprehensive framework to explore the cost-effectiveness of transit incorporating mobility-on-demand (TIMOD) in comparison to that of other alternatives, including fixed-route transit services, driving alone, and using commercial ride-hailing services (i.e., transportation network companies (TNCs)); and 2) applying the refined framework to six suburban and rural areas and shedding light on the potential benefits and trade-offs of providing TIMOD services in low-density settings. The study addresses the following questions:

- What methods allow for consistent measurement and meaningful comparison of the economic costs across various mobility services?
- From a societal perspective, accounting for both internal transportation costs incurred by travelers and service providers, as well as external costs stemming from associated externalities, what factors influence the relative cost-effectiveness of different mobility options? For each alternative, what are the key cost components?
- How does the cost-effectiveness of mobility alternatives differ across low-density areas, and what underlying factors drive these variations?
- What are the implications of the results of these analyses for future transportation planning and policy making with regard to mobility services for suburban and rural communities?

Methods

To address the questions above, the research team collected and analyzed trip data from six TIMOD programs in Washington State, to estimate the cost of TIMOD trips compared to trips made by other travel modes. The case studies consisted of suburban and more remote areas. These areas are characterized by relatively low population density compared to dense urban centers and vary in demographics, transit accessibility, and built environment features.

The project team addressed the research questions with two methodological components. First, we substantiated and enriched a conceptual framework for evaluating cost-effectiveness from a societal perspective, taking into account variations in users' socioeconomic backgrounds and travel demand levels. The variables in the measurement of cost-effectiveness are: 1) users’ (i.e., travelers) generalized costs, which consist of monetary costs and values of travel time (waiting time, in-vehicle travel time, access time, and egress time); 2) service provider's (e.g., transit agency) costs, which include the costs of labor (i.e., drivers, service managers, and planning staff), fuel/propulsion, capital, and maintenance; 3) externalities, including costs for emissions (the primary focus of our empirical analysis), crashes, noise, congestion, and benefits for health impacts. Second, we developed a traffic simulation procedure that allows transit agencies to empirically compare the costs of TIMOD with those of other alternative modes. For traveler costs, we used actual TIMOD trip data and simulated travel times for the alternative modes under the counterfactual scenario where TIMOD was unavailable. An open-source simulation software, SUMO, was used to estimate travel times for fixed-route transit and driving alone. For service provider costs, we worked with the collaborating transit agencies to obtain cost measures for TIMOD and fixed-route services.

RESULTS AND POLICY IMPLICATIONS

By estimating and comparing the total generalized cost for TIMOD and alternative modes for a representative operation day, we found the following:

- Driving alone generates the lowest generalized travel cost given time and monetary expenses (assuming all travelers have access to automobiles).
- From society's perspective, TIMOD has a comparative cost disadvantage in relation to that of other alternatives. This is mainly due to its higher service operating costs.
- From a traveler's perspective, TIMOD demonstrates a competitive advantage over fixed-route transit and TNCs. TIMOD's demand-responsive nature coupled with subsidized fare make it a comparatively low-cost option for the users.
- For the transit agency, the operating costs associated with TIMOD are, in some cases, much higher than those of fixed-route transit services. For TNC, ride-hailing fare paid by riders is assumed to fully capture the service operating cost.

While the results showed that TIMOD services can provide a more convenient and affordable travel option for residents of suburban areas with lower population density and limited transit services, they can be more expensive to operate than fixed-route transit services, especially in lower-density areas. Hence, transit agencies need to carefully design and operate these services, considering variations in travel demand and residents' sociodemographic characteristics. Future research should investigate alternative scenarios of transit service frequency and coverage, as well as parking facilities and charges near major transit stations. Moreover, further studies can look into different ways to optimize the deployment of TIMOD services to make them comparatively more cost-effective.

1 INTRODUCTION

Public transportation in areas with low population density encounters distinct difficulties due to dispersed settlement patterns and limited demand for transit services (Bronsvoort, et al., 2021; Tirachini and Cats, 2020). In such contexts, residents often struggle to access essential destinations like healthcare facilities, educational institutions, and shopping areas via public transit (Pucher and Renne, 2005). Conventional fixed-route systems are generally inefficient and cost-ineffective in these areas, and they often fail to adequately serve residents' mobility needs, resulting in limited mode shift from single-occupancy vehicles (SOVs) to public transit (Bronsvoort, et al., 2021; Pucher and Renne, 2005). A survey found that nearly 50 percent of municipalities with populations under 2,500 lack public transit services, compared to 29 percent in areas with 2,500 - 49,999 residents (Dumas, et al., 2021). Low-density areas are significantly more likely to be transit-underserved than high-density ones. These limitations drive transportation planners to explore alternative service models capable of providing more adaptive and cost-effective mobility in areas where fixed-route transit underperforms.

The proliferation of app-based ride services has opened new possibilities for public transit agencies to collaborate with innovative mobility providers. These partnerships offer flexible and demand-responsive services that can enhance existing public transportation systems (Clewlow and Mishra, 2017; McCoy, et al., 2018; Schaller, 2018; Shen, et al., 2021; Yan, et al., 2019; Wang and Shen, 2023). Demand-responsive transportation (DRT) —including ride-hailing services operated by transportation network companies (TNCs), as well as transit agency-provided on-demand and dial-a-ride programs—offers potential solutions for addressing first-mile/last-mile (FM/LM) gaps, facilitating guaranteed ride-home services, and replacing underperforming fixed-route services in low-demand areas (Bronsvoort, et al., 2021; Wang and Shen, 2023; Maretić and Abramović, 2020). These services can be tailored based on demographic and environmental considerations to improve accessibility and system efficiency (Dytckov, et al., 2022).

This study adopts the concept of Transit Incorporating Mobility-on-Demand (TIMOD), introduced by Wang and Shen (2023), to describe programs in which transit agencies integrate DRT services into their operations, either as supplements or substitutes for traditional fixed-route services. TIMOD constitutes a distinct subcategory within the broader spectrum of DRT, distinguished by public transit agency leading service design, funding, and management, with technical support provided by private companies. TIMOD services include both dynamically dispatched on-demand trips and pre-scheduled services, offering flexible options to accommodate travelers' demand. Microtransit refers to a flexible, on-demand transportation service that has flexible routes, stops and schedules. Riders schedule pick-up and drop-off times and locations in advance. Microtransit is the most common form of TIMOD, though vehicle type and service configurations may vary by area and travel demand level. For example, some TIMOD programs may utilize larger vehicles than those used in typical microtransit operations. While other forms of demand-responsive and flexible transit share operational features—such as flexible routing and dynamic scheduling—with TIMOD, these services are typically booked in advance and not always operated on a real-time basis.

A growing number of transit agencies have started piloting TIMOD initiatives, most commonly to strengthen FM/LM connections, which is one of the major barriers to increasing transit ridership (Curtis, et al., 2019). TIMOD has also been implemented in low-density and suburban areas where maintaining high-quality fixed-route service is economically unsustainable due to sparse demand and high per-passenger service costs (Shen, et al., 2021; Wang and Shen, 2023; Maretić and Abramović, 2020). Although TIMOD offers a promising solution for improving mobility in such contexts, its cost-effectiveness is influenced by a range of sociodemographic, built environment, and service operational variables. Therefore, rigorous evaluation of cost-effectiveness of TIMOD services and other mobility alternatives is essential for identifying the conditions under which these services can be more effectively deployed. This is critical to inform strategic decision-making and support the integration of economically sustainable mobilities into broader public transportation networks. Cost-effectiveness analysis (CEA) provides a systematic approach to comparing alternative services based on their relative costs and benefits, thereby supporting evidence-based policy and investment decisions.

Despite increasing interest in TIMOD, the literature on its cost-effectiveness remains relatively sparse. Wang and Shen (2023) proposed a foundational framework for assessing TIMOD's cost-effectiveness relative to other transportation modes. Cai et al (2025) further develop this framework by integrating a more comprehensive measurement of transportation externalities and a broader comparison across alternatives, including TNC services. The improved framework would allow for comparative evaluations of various mobility services across different low-density areas. However, further development is needed, particularly through the incorporation of more low-density cases with different sociodemographic, environmental, and service operational contexts. Current understanding regarding the contextual conditions necessary for the cost-effective deployment of TIMOD and its alternative modes, especially in various low-density environments, needs further exploration. Identifying the strengths and limitations of existing service models in diverse geographic settings is critical to optimizing deployment strategies and ensuring these services deliver the greatest benefit in a financially sustainable way. Beyond the scope of FM/LM trips linked to transit stations, this study examines point-to-point travel within the designated TIMOD service areas. For these point-to-point trips, passengers are required to walk to pre-assigned pick-up locations designated by the service provider before beginning their trips. The assigned pick-up locations may be situated anywhere within the service area or at designated spots located several minutes' walking distance from the requested places.

This study aims to advance the existing evaluation framework by broadening the comparison of mobility alternatives and extending the application of the framework to diverse low-density settings. The study also incorporates a more comprehensive measurement of transportation externalities, including air pollution, greenhouse gas emissions, crashes, congestion, noise, and health impacts associated with physical activity. Five distinct low-density areas in Washington State, U.S. are examined, where TIMOD services have been implemented. Although these areas are characterized by relatively low population density compared to dense urban centers, they differ in terms of demographic profiles, transit accessibility, and built environment features. Utilizing real-world TIMOD trip data from these settings, the cost-effectiveness of TIMOD services in comparison to counterfactual alternatives is evaluated. The alternatives include fixed-route transit, private vehicle use, and commercial ride-hailing services (i.e., TNCs). The analysis compares actual TIMOD trips with simulated trips using alternative modes to assess the relative efficiency of TIMOD within the existing transportation system. We aim to quantify the economic impacts of providing different mobility options on travelers, service providers, and society at large through comparative cost analysis of accommodating marginal travel demand. The study aims to address the following questions: 1) What methods allow for consistent measurement and meaningful comparison of the economic costs across various mobility services? 2) From a societal perspective, accounting for both internal transportation costs incurred by travelers and service providers, as well as external costs stemming from associated externalities, what factors influence the relative cost-effectiveness of different mobility options? For each alternative, what are the key cost components? 3) How does the cost-effectiveness of mobility alternatives differ across low-density areas, and what underlying factors drive these variations? The findings can assist transit agencies and planning organizations in exploring and implementing innovative transit solutions both within the region and in broader contexts.

The remainder of this report is organized as follows. Section 2 reviews relevant theoretical and empirical literature on demand-responsive transportation (DRT), with a particular emphasis on TIMOD services and their comparative cost-effectiveness relative to alternative mobility options. This review establishes a foundational context for the study. Section 3 outlines the methodological approach, including the conceptual framework, case study background, TIMOD service data, and the methods employed for cost-effectiveness evaluation. Section 4 presents the evaluation results, detailing total costs incurred by travelers, service providers, and environmental and health-related externalities. These costs are analyzed for an average rider across seven low-density case study areas in Washington State, with comparisons made to highlight variations associated with population density, income, and transit service levels. A sensitivity analysis is also conducted to examine the impact of key parameters on the cost-effectiveness outcomes. Section 5 provides a discussion of the findings, evaluating the economic competitiveness of TIMOD relative to other alternatives and assessing the robustness of the results to underlying assumptions. Finally, Section 6 concludes the report by summarizing the key insights derived from the study.

2 LITERATURE REVIEW

2.1 TRANSIT INCORPORATING MOBILITY-ON-DEMAND TRANSPORTATION

Information and communication technology (ICT) advancements changed mobility services, resulting in a new class of private mobility providers that leverage mobile apps and digital platforms to connect riders. These demand-responsive services, including ride-hailing, ridesharing, car-sharing, microtransit, and micromobility, provide attractive features such as enhanced flexibility, comfort, and operational efficiency. By incorporating these new mobility services, transit agencies can achieve some crucial goals, such as filling service gaps, increasing demand-responsive options, and lowering the costs of certain services (Schaller, 2018; Yan, et al., 2019; Circella and Alemi, 2018; Feigon and Colin, 2016). Figures 2.1 through 2.3 show some examples of TIMOD vehicles.

Figure 2-1. A Community Transit Zip shuttle

Figure 2-2. An Island Transit Go! on-demand shuttle

Figure 2-3. A Link Transit shuttle

The vehicles range from small passenger vans up to larger shuttle buses that can seat up to 20 people. All TIMOD vehicles are equipped with wheelchair lifts and securement systems.

Many public transit agencies have recognized this potential and have started exploring, testing, or even implementing partnerships with private entities to deliver demand -responsive mobility services (Curtis, et al., 2019; Ashour and Shen, 2022). Numerous studies have explored the conditions under which these collaborations are most effective. Researchers examining DRT public-private partnerships in the United States have identified four key service models: first-mile/last-mile (FM/LM) services connecting to transit systems, door-to-door services in low-density areas, off-peak hour services, and paratransit (Patel, et al., 2022; Lucken, et al., 2019). For instance, Southeastern Pennsylvania Transportation Authority (SEPTA) initiated a partnership with UberX in 2016 to enhance access to its rail stations and fill FM/LM gaps. Similarly, the Metropolitan Transit System (MTS) in San Diego offered a $5 discount on FM/LM connections to and from its transit stations during certain events (Lucken, et al., 2019). Moreover, many pilot projects target low-density areas. Dallas Area Rapid Transit (DART) aimed to integrate TNCs (Uber and Lyft) and other DRT providers like carpool services and bike-share programs to replace inefficient fixed-route services in low-density areas (Patel, et al., 2022; Cordahi, et al., 2018). Austin's transit agency, in collaboration with TNCs, offers both FM/LM and door-to-door microtransit services to low-density areas (Zuniga-Garcia, et al., 2022).

Lessons learned from the literature on DRT public-private partnerships include the following: 1) If transit agencies play a leading role in partnerships, they can gain better control over current DRT service provisions, ensure data accessibility, manage fare integration across transportation systems, and plan for future integration of DRT services into public transportation networks (Lucken, et al., 2019; Patel, et al., 2022). However, limited research exists on the integration of DRT services under transit agency leadership. 2) Accurate metrics and measures are critical for assessing the performance of DRT services and identifying opportunities for operational improvements (Martin et al., 2021). Evaluation results can inform decision-makers, enabling collaborations with stakeholders to achieve societal benefits such as increased ride sharing and decreased environmental externalities (Rupert, 2020). 3) The transferability of evaluation results from a pilot program to other regions should be explored to provide guidance for future projects (Cordahi, et al., 2018; Patel, et al., 2022).

Building on these studies, Wang and Shen (2023) proposed the concept of TIMOD and explored how transit agencies may play the leading role in integrating public transportation with demand-responsive mobility services. Compared to demand-responsive transit, flexible transit, and microtransit, TIMOD primarily uses minivans, offering greater adaptability to demand variability through more customized and economical vehicle sizes. It also offers enhanced routing flexibility strategically planned by transit agencies, extending beyond first-mile/last-mile connections to include point-to-point trips from origins to destinations, to accommodate local travel demand. Some areas use small buses instead of minivans. However, this emerging concept remains insufficiently explored, necessitating further studies to examine diverse scenarios and assess how TIMOD services can more effectively serve communities with varying sociodemographic characteristics and built environments, and deliver maximum societal benefits.

2.2 Evaluation of TIMOD

Several studies have highlighted potential challenges in integrating DRT services into transit systems. Patel et al. (2022) identified the most prevalent issues as ensuring equitable access to services and accurately estimating the costs of service provision. Zhou (2019) and Yan et al. (2019) demonstrated that low-demand transit routes could be replaced by TNCs at lower costs, with the primary benefit stemming from reduced wait times. However, this replacement faces practical challenges, including barriers to information sharing between public agencies and private companies, social equity issues, financial and legal concerns associated with integrating private ride-sharing services into public transit systems (Zhou, 2019). Shen et al. (2018) and Gurumurthy et al. (2020) employed agent-based modeling to examine deployment scenarios where DRT services could either support FM/LM connections to the transit system or serve door-to-door trips. Their findings suggest that subsidized DRT services for FM/LM trips can enhance transit coverage and shift demand away from private vehicle use, yielding potential performance gains. However, subsidizing DRT services for door-to-door trips in dense areas without restrictions may significantly reduce transit demand. Additionally, studies have shown that residents who frequently use ride-hailing services and live in areas with low transit service density are more likely to prefer demand-responsive services over fixed-route transit (Wang et al., 2022; Yan et al., 2021). However, for low-income travelers, limited access to reliable technological resources can pose a significant barrier to adopting these services (Wang et al., 2022).

While these studies provide initial insights into the integration of DRT services, they failed to discuss the potential advantages for transit agencies in leading the integration. Furthermore, these studies were exploratory and had limitations restricting their applicability in guiding transportation decision-making. Some studies used simulations based on hypothetical scenarios, which may only partially reflect the complexities of designing and implementing TIMOD. Other studies relied on respondents' stated preferences, which may not always align with their actual behavior for various reasons such as habit, convenience, or external factors. A recent study conducted by Wang and Shen (2023) used real-world TIMOD trip data to evaluate the service performance with respect to the costs of travelers, service providers, and society. By analyzing real behavior and outcomes, transportation researchers can better understand the comparative cost-effectiveness of TIMOD services and better inform relevant decision-making. Nevertheless, a more comprehensive list of cost components, particularly the external costs associated with different travel modes, should be considered to assess the comparative cost-effectiveness of TIMOD services across various geographic contexts.

2.3 Cost-Effectiveness of TIMOD Services

The comparative cost-effectiveness of providing mobility options in low-density areas has been a topic of interest in transportation research. One study highlights the cost-effectiveness challenges of fixed-route transit in low-demand and sparsely populated areas (Bauchinger, et al., 2021). The authors argue that demand-responsive services can be a more cost-effective alternative in such areas compared to solely operating conventional transit systems. Another study argues that fixed-route services are expensive and do not provide good service at nighttime in low-density areas. In contrast, demand-responsive services with flexible and dynamic routing systems are more cost-effective in these areas (Sanaullah, et al., 2021). These studies highlight the potential cost-effectiveness of TIMOD services relative to fixed-route transit. However, more explicit estimations from the perspectives of travelers, service providers, and society are required to substantiate the findings.

Both traveler's time costs and service provider's operating costs are critical for evaluating the cost-effectiveness of a transportation mode. Some studies have focused on the costs incurred by service providers, aiming to optimize service supply. These studies typically assume that service providers bear all service-related expenses and manage vehicle assignments in response to incoming requests. The optimization generally includes the provider's operating costs (such as vehicle dispatch, fleet size, and labor) and users' time costs (including waiting and in-vehicle times) (Quadrifoglio and Li, 2009; Nourbakhsh and Ouyang, 2012; Grahn, et al., 2022). In contrast, other studies have focused exclusively on minimizing users' costs, arguing that fixed-route transit increases users' access and egress times due to its fixed pick-up and drop-off locations (Kumar and Khani, 2021).

The value of travelers' time varies across different time components of a trip, including access time, waiting time, in-vehicle time, and egress time. However, some factors that could affect travelers' costs, such as perceived discomfort during the trip and the freedom to arrange waiting time, are often overlooked in literature. Additionally, service performance under varying levels of demand density has been explored (Zhou, 2019; Nourbakhsh and Ouyang, 2012). These factors should also be considered when evaluating the cost-effectiveness of a mode of transportation.

To quantify transportation externalities, previous studies have employed modeling software such as SUMO for microsimulation and MATSim for large-scale simulation. These tools simulate externalities such as emissions, noise, and congestion for individual vehicles under specific scenarios, and results are then aggregated for further analysis (Rendel and Bachmann, 2023). Other studies have directly utilized historical data to estimate externalities across entire transport systems (Schröder, et al., 2023). These studies provide useful information about externalities in large-scale transportation systems using aggregated traffic data. However, estimating and monetizing the effects of individual trips on transportation externalities remain challenging, necessitating further adjustments of relevant parameters tailored to the specific contexts of different study cases.

3 Data and Methodology

3.1 Case Background and Data

This study evaluates the comparative cost-effectiveness of TIMOD services in six representative low-density areas in Washington, including Leavenworth, Chelan, Lynnwood, Bainbridge Island, Kingston, and Whidbey Island (see Figure 3-1). TIMOD services claim to offer convenient, fast, and affordable rides in the designated areas. Depending on the area, riders either pay a fare equivalent to the bus fare or can use these services for free. The vehicle capacity and the maximum number of passengers per ride also vary by area, typically ranging from six to 14 seats. The service also provides ADA-accessible vehicles for passengers with mobility devices. Service hours vary depending on the location. The service can be booked through either an app or a phone call, with pick-up and drop-off times available upon request. TIMOD provides point-to-point demand-responsive services within the designated service area limits, irrespective of the trip purpose.

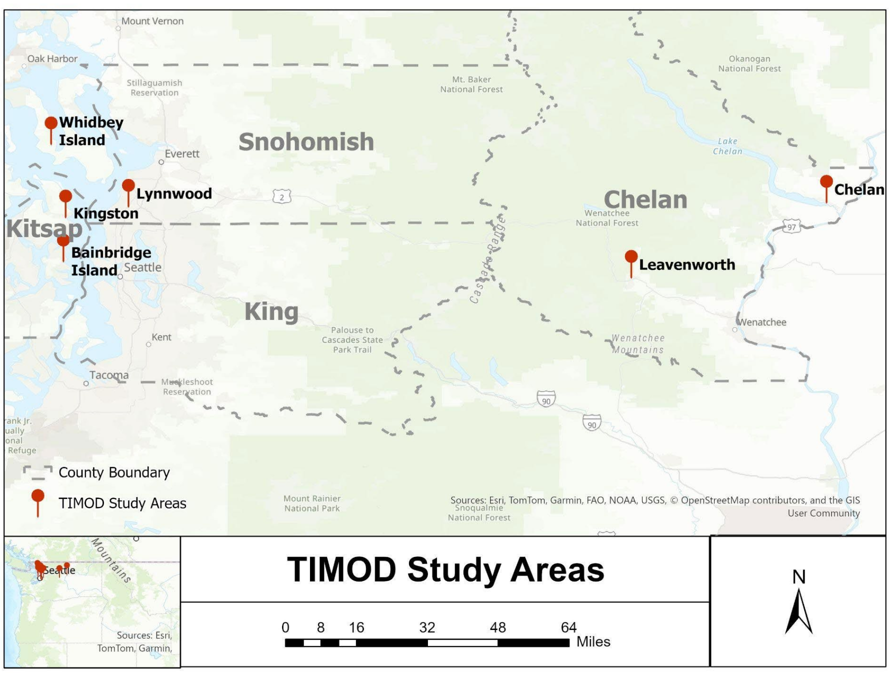

Figure 3-1. The areas of study

The trip-level data for completed rides consists of request, pick-up, and drop-off times, origin and destination geo-coordinates, trip distances, and the number of seats requested. A representative day is selected for each of the case areas to estimate the comparative cost-effectiveness of mobility alternatives on that day. The selection is based on the most recent date when the ridership started to stabilize and reached the average level over time. The case areas' sociodemographic characteristics are obtained from the 2019-2023 American Community Survey (ACS) 5-year estimates and the 2024 Labor Statistics (U.S. Census Bureau, 2023; Bureau of Labor Statistics, 2024), as well as the characteristics of TIMOD service operation and the selected representative days of trip data are shown in Tables 3-1 through 3-4.

Table 3-1. Urban hierarchy of the service areas (WSDOT, 2024)

Service provider	Link Transit	Community Transit	Kitsap Transit	Island Transit
Urban hierarchy of the service areas[1]	Small Urban	Urban	Small Urban	Rural
Location of service areas	Leavenworth and Chelan	Lynnwood	Bainbridge Island and Kingston	Whidbey

Table 3-2. Transit sociodemographic characteristics

Sociodemographic characteristics	Leavenworth	Chelan	Lynnwood	Bainbridge Island	Kingston	Whidbey Island
Median hourly wage[2]	\$23.04	\$23.04	\$32.46	\$29.37	\$29.37	\$24.24
Population density (sq. mi)	1,841	644	5,199	891	1,225	1,637
Median age	42.3	46.7	39.2	49	40.6	30
Ratio of bachelor's degree or higher	45.6%	26.5%	32.6%	75.0%	42.4%	26.66%
Median household income (\$)	\$74,653	\$71,996	\$76,439	\$159,882	\$99,345	\$72,000

Table 3-3. Transit TIMOD service operations

TIMOD Service operation	Leavenworth	Chelan	Lynnwood	Bainbridge Island	Kingston	Whidbey Island
Service hours	5:30am - 8:30pm	7:30am – 6:00pm	5:00am – 10:00pm	8:00am - 6:30pm	7:30am – 5:00pm	5:00am – 8:00pm
Service type	Point-to-point	Point-to-point	Point-to-point	Point-to-point	Point-to-point	Bus stop-to-bus stop
Vehicle capacity	14	14	6	14	14	8
Vehicle type	Bus	Bus	Minivan	Bus	Bus	Small bus

[1] WSDOT defines rural transit service areas as regions with populations of 50,000 or fewer, which is the same as the definition reported by the Federal Highway Administration (FHWA Highway Functional Classification Concepts, 2013). This definition differs from that used by the U.S. Census Bureau.
[2] The median hourly wages are available at the level of metropolitan statistical areas, which do not correspond with the median household incomes that are the ACS data.

Table 3-4. Transit trip level data

Trip-level data	Leavenworth	Chelan	Lynnwood	Bainbridge Island	Kingston	Whidbey Island
Number of trips on the representative day	38	38	193	61	13	18
Number of riders on the representative day	38	41	206	91	13	18
Period of data availability	Feb 1, 2024 – Mar 23, 2024	Feb 1, 2024 – Mar 23, 2024	Jan 1, 2024 – Dec 31, 2024	Jan 1, 2024 – Dec 31, 2024	Jan 1, 2024 – Dec 31, 2024	Jan 1, 2025 – Apr 30, 2025
Selected representative day	Wed, Feb 28, 2024	Wed, Feb 28, 2024	Tue, Sep 10, 2024	Wed, Sep 4, 2024	Wed, Sep 4, 2024	Wed, Apr 30, 2025

3.2 Methodological Framework

This study builds upon an analytical framework proposed by Wang and Shen (2023) for quantifying and comparing the economic costs of expanding mobility services in new or underserved areas. The framework emphasizes using marginal cost instead of system-wide average cost when considering service expansion or new mobility options, as it provides more pertinent information for decision-making. “Marginal cost” refers to the costs for serving an increment of trips generated by an additional group of travelers. The framework also highlights the importance of accounting for both the service provider's and the users' costs, including monetary and time costs, and externalities such as environmental impacts. To accurately estimate the user's travel time, the time cost should include access, waiting, in-vehicle, and egress times. The framework is shown in Figure 3-2.

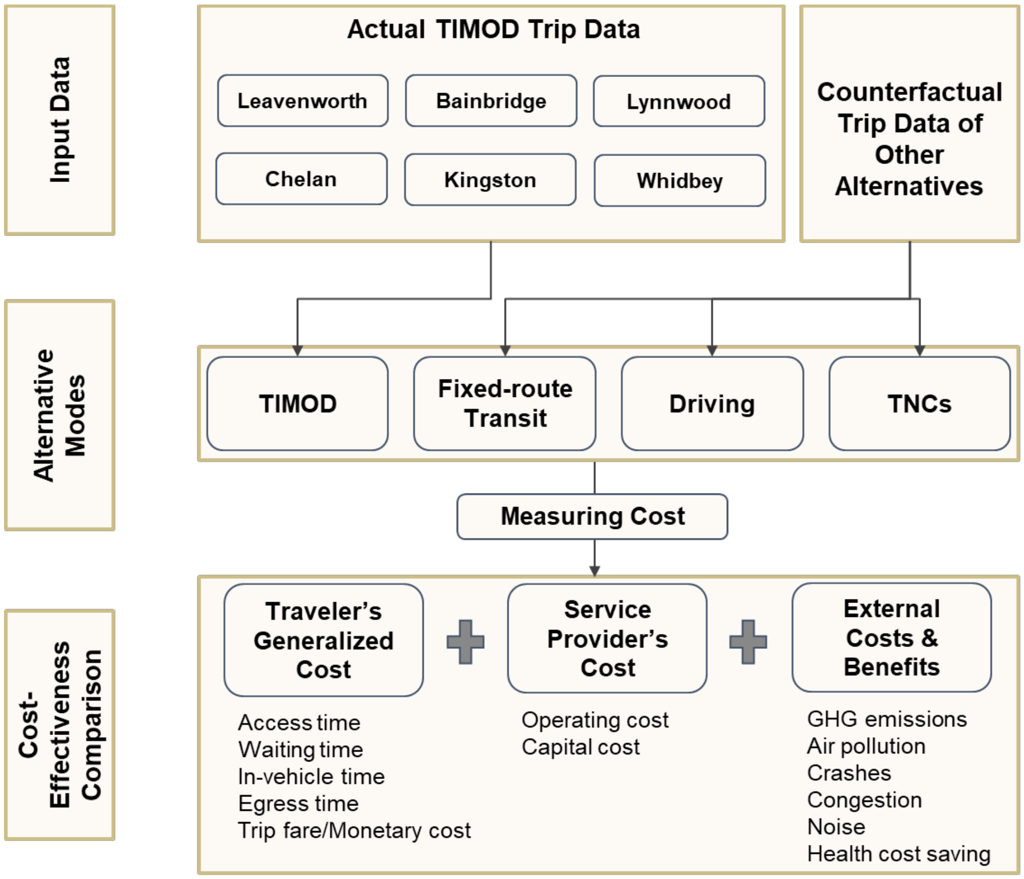

Figure 3-2. Methodological framework

The study addresses the research questions with two methodological components. First, the evaluation of alternative travel modes' cost-effectiveness is conceptualized from a societal perspective by considering traveler's generalized cost, service provider's cost, and transportation external costs and benefits. Second, a transportation simulation procedure is built to allow transit agencies to empirically compare the costs of serving TIMOD trips to the counterfactual trips of other mobility alternatives: 1) fixed-route transit, 2) driving, and 3) commercial ride-hailing services (i.e., TNCs). Specifically, the traveler's generalized cost is estimated by monetizing actual travel times of TIMOD trips and simulated travel times of the counterfactual trips of other alternatives. Travel times are monetized using travelers' values of time as percentages of the median hourly wage in each area. The service provider's cost is estimated using the statistics obtained from collaborating transit agencies. The transportation externalities include air pollution (harmful air pollutants), greenhouse gas emissions, crashes, congestion, noise, and health benefits from physical activity associated with active modes of travel.

3.2.1 Conceptualizing Cost-Effectiveness of Alternative Travel Modes

Economic cost variables are quantified to assess the cost-effectiveness of TIMOD relative to alternative modes. These variables include:

1. Generalized costs for travelers from different socioeconomic backgrounds include travel time components, such as access time, waiting time, in-vehicle time, and egress time, and monetary costs, such as ride fares or parking fees.
2. Costs for mobility service providers, including public transit agencies and private operators. These typically cover the costs of labor (wages for drivers, managers, and planners), fuel or propulsion, capital, and maintenance.
3. Costs and benefits of transportation externalities, primarily environmental and health externalities.

3.2.2 Estimating Travel Times and Costs

Figure 3-3 illustrates the simulation framework. Because TIMOD is a shared-ride service, users can either request specific pick-up locations or be directed to walk to a designated spot at a nearby corner. For the cases where pick-up locations as requested can be almost anywhere within TIMOD service areas, the access time of a TIMOD trip is estimated as the interval between pick-up arrival and departure time. If pick-up arrival time equals departure time, it means the access time would be zero. The waiting time of a TIMOD trip is estimated as the interval between reported pick-up arrival time and promised pick-up time. If the reported pick-up arrival time is earlier than the promised pick-up time, the waiting time is assumed to be zero. The above estimation methods of access time and waiting time apply to the cases of Leavenworth, Chelan, Lynnwood, Bainbridge Island, Kingston, and Whidbey Island.

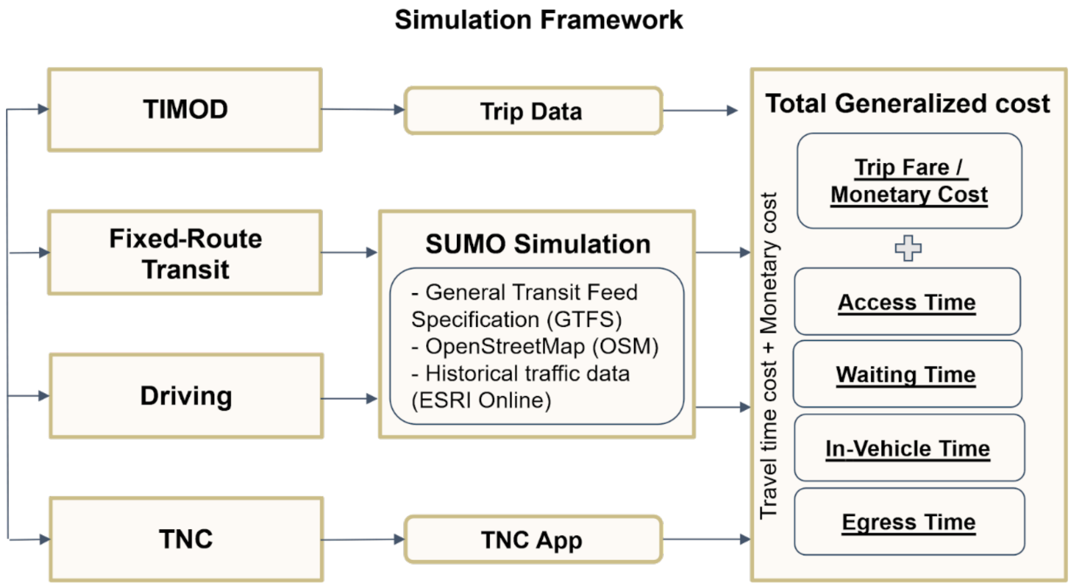

Figure 3-3. Alternative modes simulation framework

Based on actual TIMOD trips, the counterfactual trips by other alternative travel modes are simulated by using Eclipse SUMO, a free and open-source software. Eclipse SUMO is highly customizable and can directly model real-world road networks and individual-traveler-level traffic flows (Lopez, et al., 2018). It allows the data import of bus schedules and road network to simulate the trips of fixed-route transit and driving. Data for bus schedules is obtained from General Transit Feed Specification (GTFS). Road network data is from OpenStreetMap (OSM), including the number of lanes, speed limits, permitted vehicle types, sidewalks, pedestrian crossings, and traffic signals. In simulating counterfactual trips by fixed-route transit and private vehicle, it is assumed that travelers would depart at the same time as when they requested TIMOD services. Depending on the departure time, an estimated speed factor is applied to each trip to account for varying traffic speeds throughout a typical weekday. The speed factor reflects the ratio of traffic speed at a certain time of day to the road speed limit. It is estimated based on historical traffic data from ESRI online[3]. The outputs of the simulation include access, waiting, in-vehicle travel, and egress times required for travelers using each mode.

[3] Retrieved from: https://pro.arcgis.com/en/pro-app/latest/help/data/streetmap-premium/use-live-traffic-with-streetmap-premium.htm

Travel times and costs of TNC trips are estimated using Uber's Guest Trip Estimates endpoint[4]. It returns estimated waiting time, trip duration, and trip fare based on the input of trip information, including addresses of origin (pick-up location) and destination (drop-off location), along with trip departure time. It is assumed that the trips would occur on a similar weekday and during the same time period as the actual TIMOD trips. The option with the lowest price is selected for the estimation of each trip. The study also assumes that travelers who choose TNC would spend similar time on accessing their pick-up locations as the corresponding TIMOD trips.

3.2.3 Estimating the Generalized Costs for Travelers

Travel time for each mode was monetized using percentages of the median hourly wage rate as the values of travelers' time during trips, under the simplified assumption that the trips were either commuting trips or non-commuting trips made by average working adults during a typical weekday. Travelers' values of time for various trip components are listed in Table 3-5. These values were determined for the following reasons:

1. The U.S. Department of Transportation recommended plausible ranges for personal trip values of travel time savings for surface modes other than high-speed rail (U.S. Department of Transportation, 2016). These were 35 percent to 60 percent of hourly earnings for time spent in a vehicle and 80 percent to 120 percent of hourly earnings for time spent on walking.
2. For the value of in-vehicle time as a percentage of hourly earnings, TIMOD and TNCs were assigned the lowest value rounded to the nearest 10 (i.e., 40 percent), while driving was assigned the highest value (60 percent) (Wang and Shen, 2023). TIMOD and TNC vehicles were expected to have a higher level of comfort than buses given their available seats for all passengers, which contributes to their lower opportunity cost of in-vehicle time than transit. Compared to other modes, drivers of private vehicles cannot use their in-vehicle time freely, and therefore they were expected to have the highest opportunity cost of in-vehicle time.
3. TIMOD and TNC were also set to have a lower wait time value than transit (Schwieterman, 2019). TIMOD and TNC riders have more control over the distribution and use of their time waiting and walking to pick-up locations. Even if

[4] Retrieved from https://www.uber.com/global/en/price-estimate/; https://developer.uber.com/docs/guest-rides/references/api/v1/guest-trips-estimates-post

they were a few minutes later than the estimated pick-up time, drivers would stay for a short time (about 2 minutes) to allow riders to arrive at pick-up locations. In contrast, bus arrival times are less predictable compared to on-demand modes (e.g., TIMOD and TNC). The psychological cost of uncertainty for fixed-route transit riders increases the perceived cost of waiting time. Additionally, travelers tend to perceive waiting time as more onerous than in-vehicle time, and this disutility is typically higher for bus services due to less reliability compared to other modes.

4. Due to the lack of information about the ultimate destination, the egress walking time is assumed to be zero for TIMOD and TNC. For most cases, the drop-off locations are believed to be quite close to the eventual destination. The egress walking time for bus trips is included as part of the total walking time, alongside access walking time.

Table 3-5. Travelers' values of time for trip components as percentages of hourly wage

Time components	TIMOD	Fixed-route transit	TNC	Driving
Access time	100%	100%	100%	100%
Waiting time	50%	75%	50%	NA
In-vehicle time	40%	50%	40%	60%
Egress time	NA	100%	NA	100%

TIMOD ride fare per person of each case area is shown in Table 3-6 in Section 3.2.4. Trips made by driving do not have to pay a ride fare. Instead, these trips pay for the costs of fuel consumption, maintenance, and vehicle ownership divided by the miles traveled. The gasoline price per gallon of each area is estimated as the average price of local gas stations. They are Leavenworth ($4.63), Chelan ($4.02), Lynnwood ($4.02), Bainbridge Island ($4.32), and Kingston ($3.82), and Whidbey Island ($3.73)[5]. Fuel consumption from driving is estimated using SUMO simulation, which accounts for the effects of vehicle speed and acceleration on fuel usage during a trip (Krajzewicz, et al., 2014). Additionally, the average costs of car maintenance and car

[5] These figures are obtained from https://www.gasbuddy.com/gasprices/washington/

ownership (including insurance, license, and depreciation[6]) are respectively \$0.101[7] and \$0.854[8] per mile in 2024 (AAA, 2024).

3.2.4 Estimating Service Provider's Operating Costs

The operating cost per vehicle per hour of TIMOD service in each case area is also shown in Table 3-6. The data for TIMOD operating costs is obtained from the transit agencies. The TIMOD operating cost typically includes wages for drivers, dispatchers, and immediate supervisors, as well as costs of maintenance, fuel, and insurance divided by the hours of service. For the estimation of counterfactual operating costs of fixed-route transit, it is assumed that an increase in passengers would necessitate additional investments in the current transit system if TIMOD option is unavailable, such as using larger buses and adding more seats. Due to the lack of available data to quantify this additional investment, the current operating cost allocated to the number of TIMOD riders was used as an approximate estimate of the marginal cost of accommodating this additional amount of travel demand within the transit system. Given this assumption, the agency's total operating costs for TIMOD and transit are calculated using equations (1) and (2). The total vehicle hours of TIMOD service on the selected day are provided by the collaborating transit agencies. The total vehicle hours of fixed-route transit and the average weekday transit boardings in the month of the selected day were also obtained from the collaborating transit agencies.

Table 3-6. Service operation by case area

Transit Agency	Link	Link	Community	Kitsap	Kitsap	Island
Service area	Leavenworth	Chelan	Lynnwood	Bainbridge Island	Kingston	Whidbey Island
Ride fare per person	\$0	\$0	\$2.50 or less	\$2.00 or less	\$2.00 or less	\$0
Hourly operating cost per vehicle	\$148	\$148	\$70	\$283	\$283	\$206

The equations below show how service providers' total operating costs of trips of TIMOD and fixed-route transit are measured.

$$CMF=OMF*HMF \tag{1}$$

$$C_{transit}=O_{transit}*H_{transit}*D/(R_{transit}+D) \tag{2}$$

[6] Depreciation, which reflects the portion of a car's value lost over time, can capture the portion of purchase cost allocated to the period of analysis.
[7] This was obtained by calculating the average of different vehicle types.
[8] The same as above, assuming 10,000 miles traveled per year.

where CMF is the total operating cost of TIMOD vehicles on the selected day, OMF is the TIMOD's operating cost per vehicle per hour, HMF is the total vehicle hours of TIMOD on the selected day. $C_{transit}$ is the total operating cost of buses traveling through the study areas on the selected day, $O_{transit}$ is the operating cost per bus vehicle per hour, $H_{transit}$ is the total vehicle hours of buses traveling through the study areas on the selected day, D is the total number of persons generating the demand for the observed trips of TIMOD on the selected day, and $R_{transit}$ is the total ridership of those buses on the selected day.

For driving[9], it is assumed that additional parking spaces might need to be constructed to accommodate the increased parking demand resulting from the shift of TIMOD trips to private car trips. The parking cost per space consists of land costs, construction costs, and the costs of operation and maintenance. The types of parking facilities in suburban and rural areas include on-street parking, off-street parking, surface parking (parking lots directly on land), and structured parking space (multi-story parking buildings called parkades, garages or ramps). Underground parking is assumed to be not typical in suburban and rural areas. Moreover, this study assumes that each parking space serves two trips per day and would be offered to drivers at no charge. Therefore, the minimum number of parking spaces needed in each area can be calculated based on the total number of trips. Monthly costs per parking space for different types of facilities in suburban areas are shown in Table 3-7. In addition, TNC operating costs are not known, nor are they a direct, public financial cost; they are assumed to be fully covered by fares collected from the users, which is quite reasonable because Uber only started to make a profit in 2023.

Table 3-7. Suburban-area cost per parking space by facility type in 2024, adjusted for inflation (Litman, 2022; Litman, 2025)

Type of facility	Land cost	Construction cost	Operating and maintenance cost	Total monthly cost per parking space
On-street parking	$6.18	$23.14	$26.50	$55.83
Surface parking with free land	$0.00	$38.51	$35.33	$73.85
Surface parking	$14.05	$38.51	$35.33	$87.89
Structured parking	$6.98	$115.54	$53.00	$175.52

[9] The cost of road maintenance per VMT is calculated by subtracting 2024 Highway Trust Fund outlays from receipts (-$14.01B) and dividing by the total 2024 highway VMT across the transportation system (3,279.1B). The data can be accessed from: https://data.bts.gov/stories/s/Transportation-Economic-Trends-Government-Transpor/6bdc-i7mh/.
The total road maintenance cost allocated to these trips is then computed by multiplying the cost per VMT by the total trip VMT. This cost is added to the external cost by driving.

3.2.5 Estimating Transportation Externalities

The estimation of transportation externalities includes the costs of air pollutants on health and materials, greenhouse gases on global climate and ecosystems, crashes, congestion, noise, and health impacts associated with physical activity. To estimate these externalities, vehicle miles or passenger miles of travel are converted into corresponding monetary costs by travel mode.

Greenhouse gases: Greenhouse gases have significant and far-reaching effects on the Earth's climate and ecosystems. The cost of greenhouse gases is estimated based on life-cycle CO_2 or CO_2 equivalent (CO_2E) emissions of trips by mode. While CO_2E includes CO_2 emissions and the emissions of other greenhouse gases (such as methane, nitrous oxide, or fluorinated gases), CO_2 emissions account for 95 percent of all transportation-related greenhouse gas emissions (Federal Transit Administration, 2010). In this regard, the estimates based on CO_2 and CO_2E can be considered approximate. A typical minivan (make and model: Toyota Sienna or Chrysler Pacifica) used for operating TIMOD service in some case areas would generate 502 grams[10] of CO_2E per vehicle mile traveled (which approximates to the emissions of a standard SUV), while a passenger car used by TNC and a single driver would generate 410 grams of CO_2E per vehicle mile traveled (Bieker, 2021). Furthermore, a TIMOD trip can be a shared ride, while its counterfactual trip by TNC (Uber or Lyft) or driving is assumed to be not shared by more than one rider in the study areas. Uber or Lyft do not offer ride-pooling services outside of major markets, according to the company's statement (Schaller, 2021)[11]. Compared to non-shared rides for the same level of demand, shared rides can result in fewer miles traveled with passengers in vehicles, and thus lower associated external costs. This has been considered when estimating the external costs for TIMOD and other alternatives. This study has also taken into account the effect of deadheading on the emission costs of both TIMOD services and TNCs as an additional proportion of the trip distance. According to the statistics provided by the collaborating transit agencies, the average deadhead mile ratio of a TIMOD trip on the selected day for each case area is as follows: Leavenworth (62 percent), Chelan (18 percent), Lynnwood (9 percent), Bainbridge Island (6 percent), Kingston (36 percent), and Whidbey Island (10

[10] The CO_2 emission equivalents per kilometer from the original estimates have been converted to the equivalents of per mile.
[11] The areas where the UberX Share service is available can be found at: https://www.uber.com/us/en/ride/uberx-share/. The Seattle metropolitan area is not included in this list.

percent). For TNC, the average deadhead mile ratio per trip in the Seattle Metropolitan Area is 46.9 percent (Balding et al., 2019). This ratio is assumed to apply to all other case areas outside the Seattle Metropolitan Area. From a national average perspective, a typical bus generates 291 grams of CO_2 per passenger mile traveled (APTA, 2018). CO_2 emissions were then monetized using the marginal abatement cost of $313.73 per ton of CO_2 emissions in the United States (Liu and Feng, 2018). Therefore, the CO_2 emission abatement cost of a TIMOD minivan is $0.16 per vehicle mile driven, compared to $0.13 per vehicle mile driven for a typical passenger vehicle of TNC and personal driving, and $0.09 per passenger mile traveled for a bus. We used equation (3) to estimate the emission cost of each mode.

$$CE = M * E_{mode} * L_{mode} \tag{3}$$

where CE is the CO_2 emission abatement cost of a mode, M is the abatement cost per gram of CO_2 emissions, E_{mode} is the CO_2 emission equivalents per vehicle/passenger mile traveled, L_{mode} is the total mileage, including deadheading miles, traveled by passengers on the selected day.

Air pollution: Air pollutants harm the health of humans and other living beings, as well as damage materials. Air pollutants consist of harmful gases (such as carbon monoxide, sulfur dioxide, or nitrogen oxide), particulate matter (such as PM10 or PM2.5), and biological molecules (such as volatile organic compounds). On the basis of estimates of vehicles in line with the Euro 6 emission standard for European countries, the air pollution cost per vehicle mile traveled by a small passenger car or a large SUV on an urban road is estimated as $0.0025 (European Commission, 2019; US Department of Transportation, 2021)[12]. When compared to European emission standards, U.S. Environmental Protection Agency (EPA) emissions standards for passenger cars and light-duty vehicles align most closely with the Euro 6 standard. Therefore, a typical passenger car used by TNCs and private drivers and a typical minivan used for TIMOD in some areas would generate an air pollution cost of $0.0026 per vehicle mile traveled. The air pollution cost per passenger mile traveled by bus on an urban road is estimated as $0.0015 (European Commission, 2019). These estimates are lower than the converted estimates

[12] The original estimates were reported in 2016-euro cents per passenger kilometer. These estimates have been converted to per passenger mile and per vehicle mile, respectively, by assuming an average of 1.6 passengers per vehicle (US Department of Transportation, 2021). They have also been adjusted for the exchange rate between EURO and USD in 2016 (i.e., 1 EURO in 2016 = 1.1069 USD in 2016) and for inflation from 2016 to 2024 (i.e., 1 USD in 2016 = 1.31 USD in 2024).

reported by Delucchi and McCubbin (2011) for 2006 because new emission standards for light-duty vehicles in the U.S. and Europe are set to lower air pollution emissions.

Crashes: Based on the estimates of Lemp and Kockelman (2008), the crashes cost per vehicle mile driven by a TIMOD minivan is $0.155, while it is $0.113 for a passenger vehicle of TNC and personal driving[13]. In comparison to the proportions of crash costs of light-duty passenger vehicles and heavy-duty freight trucks, only 0.7 percent of the annual crash costs for the entire U.S. vehicle fleet is attributable to buses (Delucchi and McCubbin, 2011). Because this is only a minor factor to the total external cost, we estimate the crash cost of a bus to be zero in alignment with the study of Delucchi and McCubbin. The sum of crash costs of a travel mode is calculated by the cost per vehicle mile driven times the total number of miles traveled by mode.

Congestion: Congestion cost can be estimated as the value of added delays based on the current traffic, which is a function of traffic volume relative to road capacity and the value of time spent in vehicles. Lemp and Kockelman (2008) estimated the value of added delay for different vehicle types by using their passenger car equivalents at signalized intersections on roadways with an average road capacity of 2,000 vehicles per hour per lane and under standard congested conditions (reaches 95 percent of capacity), assuming that the value of in-vehicle time was $8 per hour in 2006. The results show that the congestion cost per mile driven of a minivan (assuming the make and model are Toyota Sienna) was $0.0935 in 2006, while for a passenger car (assuming the make and model are Toyota Corolla), it was $0.0698. The 2006 values are adjusted to 2024 levels using the ratio of in-vehicle time values for those years. The estimated congestion cost per vehicle mile traveled by mode of each case area is shown in Table 3-8. The sum of congestion costs of a travel mode is calculated by the cost per vehicle mile traveled times the total number of miles traveled by mode. In addition, buses are assumed to have zero marginal impact on congestion, as their schedules are assumed to remain unchanged regardless of additional travelers[14]. Consequently, the number of bus miles does not increase, and the congestion cost for buses is considered to be $0.

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[13] The costs have been adjusted for inflation from 2006 to 2024 (i.e., 1 USD in 2006 = 1.56 USD in 2024). They were calculated using the cost of the Toyota Sienna minivan and the average cost of small cars from the original estimates, adjusted for inflation from 2006 to 2024.

[14] We acknowledge the limitation of this assumption. In reality, adding more passengers to existing buses will increase the time required for boarding and alighting at each stop. However, for a simplification purpose, we assume this difference to be negligible.

Table 3-8. Congestion cost per vehicle mile travelled by mode in 2024

Mode	Leavenworth	Chelan	Lynnwood	Bainbridge Island	Kingston	Whidbey Island
TIMOD	$0.142	$0.142	$0.201	$0.182	$0.182	$0.149
TNC	$0.106	$0.106	$0.150	$0.136	$0.136	$0.112
Driving	$0.160	$0.160	$0.226	$0.204	$0.204	$0.168

Noise: Noise cost of vehicle use depends on the density of the population exposed to the noise and the existing noise level (which is affected by the existing traffic volume, traffic speed, and mix of vehicle types) (European Commission, 2019). It varies by road type, from local roads to interstate highways. The assumed average noise cost of a light-duty vehicle is $0.064 per vehicle mile traveled and $0.040 per passenger mile traveled in 2024, assuming 1.6 passengers per vehicle (Delucchi and McCubbin, 2011; US Department of Transportation, 2021). The noise cost per passenger mile traveled by bus is similar to that of a passenger car (European Commission, 2019). Therefore, we estimate the noise cost per passenger mile traveled by bus to be $0.040.

Health cost saving: The health cost savings reflect the monetary values for the health benefits of increased walking and cycling, including the benefits internal to the people who increase their activities and external benefits to society due to medical cost savings and thus the reduction in public financial burden of illness. With inflation considered, the health cost savings per mile in 2024 are estimated at $0.29 for increased cycling and $0.72 for increased walking (LTNZ 2006; Litman, 2016). These values are multiplied by the increased walking and cycling distances associated with access to and egress from fixed-route transit to account for the resulting benefit savings. The estimated health savings are then subtracted from the sum of other external costs to determine the final external cost.

4 RESULTS

4.1 COMPARING TRAVEL TIME BY MODE OF TRANSPORTATION

Figure 4-1 shows the distributions of travelers' total travel time by transportation mode and area. Table 4-1 provides a breakdown of travel time by mode, aggregating trips across all areas. From the overall distribution of trip duration, TIMOD takes more time than driving and TNC, but less time than transit on average. Compared to driving and TNC, TIMOD trips have longer in-vehicle times due to ride sharing. TIMOD trips also have longer waiting times than counterfactual TNC trips. The longer waiting times of the TIMOD trips are due to fluctuations in demand and varying supply availability to meet the demand throughout the day. Additionally, long transit trips with extended access and waiting times reflect the limited transit service coverage in the study areas.

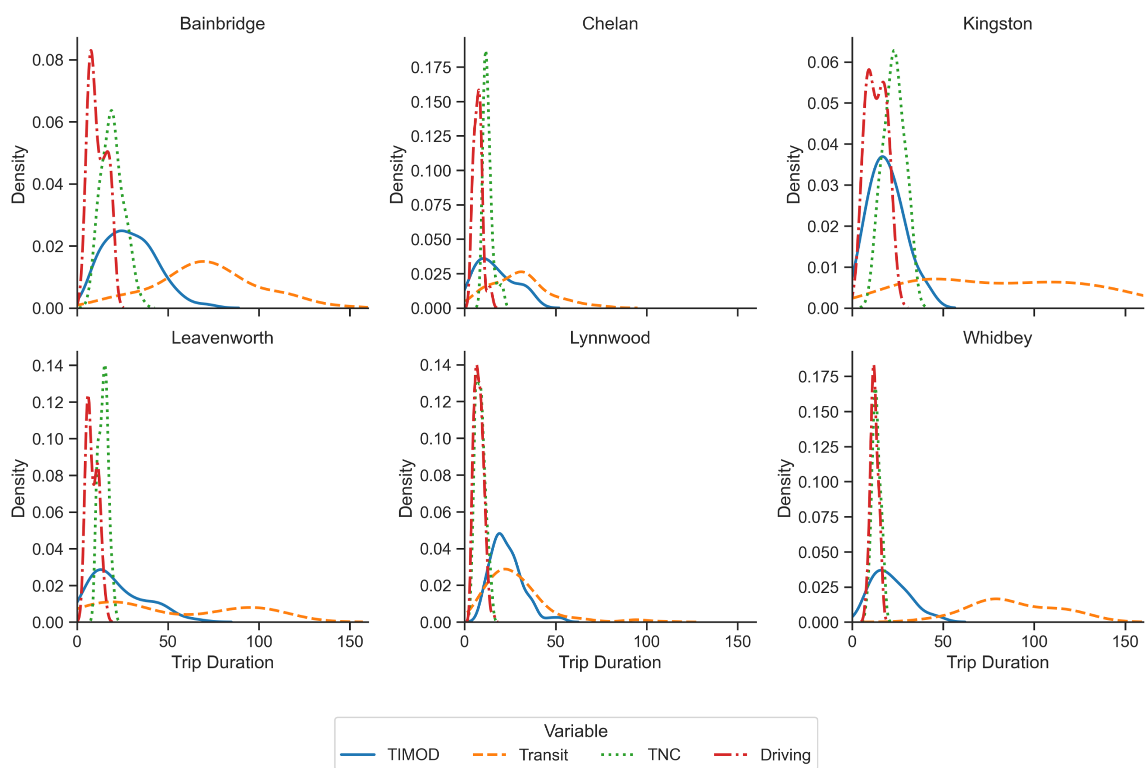

Figure 4-1. Distribution of total travel time by mode

Table 4-1. Breakdown of travel time in minutes by mode across area

Mode	Mean	Std.	Min.	Max.
TIMOD	23.22	11.18	3.00	70.70
Access time + Wait time	11.87	8.72	0.00	45.13
In-vehicle time	11.29	7.31	0.01	50.00
Transit (bus)	42.81	31.38	5.02	149.65
Access time + Wait time	39.76	30.27	5.02	144.90
In-vehicle time	3.05	4.39	0.00[15]	21.57
TNC	12.23	5.73	4.00	35.00
Access time + Wait time	4.84	4.28	1.00	23.00
In-vehicle time	7.39	3.52	1.00	19.00
Driving	8.84	3.59	3.40	21.40
In-vehicle Time	6.84	3.59	1.40	19.40
Parking Time	2	0	2	2

4.2 Costs for Travelers, Service Operation, and Externalities

Tables 4-2 through 4-6 show the costs of travelers, service operation, and externalities in total and per rider of each case area. From a societal perspective, our findings reveal that driving is the least expensive mobility option for riders across all areas even when parking costs are considered. TNC services are more cost-effective than both TIMOD and fixed-route transit. The comparative cost-effectiveness of TIMOD compared to fixed-route transit depends on the service provider's operations. In some areas, TIMOD is less costly than fixed-route transit, while in others, it is more expensive. From the traveler's perspective, TIMOD has a cost advantage over fixed-route transit and TNCs due to its demand-responsive nature and subsidized fares. In Leavenworth and Chelan, TIMOD services are even more cost-effective than driving for travelers. From the service provider's perspective, TIMOD is more costly than fixed-route transit in most areas, though it is less expensive in Bainbridge Island and Kingston. In terms of total external cost, fixed-route transit is less expensive than other alternatives. TIMOD has an advantage over TNCs, largely due to reduced VMT resulting from more common shared rides. In some areas, the use of buses instead of minivans for TIMOD service further contributes to lower external costs.

[15] The minimum in-vehicle time by fixed-route transit is zero because for some of the trips, transit is not even an option due to the limited-service coverage. In these cases, people are assumed to walk to their destinations, resulting in a long access time.

Table 4-2. Numbers of trips, riders, and parking spaces by area

Service Provider / Area	LT Leavenworth	LT Chelan	Total for LT areas	CT Lynnwood	KT Bainbridge Island	KT Kingston	Total for KT areas	Whidbey Island
Number of trips	38	38	76	195	61	13	74	18
Number of riders	38	41	79	208	91	13	104	18
Estimated parking spaces for serving mobility demand per day	19	19	38	98	31	7	37	9

Notes: LT – Link Transit, CT – Community Transit, KT – Kitsap Transit

Table 4-3. Estimated cost components for TIMOD

Cost types	LT Leavenworth	LT Chelan	Total for LT areas	CT Lynnwood	KT Bainbridge Island	KT Kingston	Total for KT areas	Whidbey Island
Travelers' generalized costs: sum	$154.79	$123.00	$277.79	$1,710.46	$768.28	$76.14	$844.41	$62.34
Travelers' generalized costs: per rider	$4.07	$3.00	$3.52	$8.30	$8.44	$5.86	$8.12	$3.47
Daily operating costs: sum	$2,326.56	$1,499.24	$3,825.80	$6,187.64	$5,094.00	$237.72	$5,331.72	$1,076.92
Daily operating costs: per rider	$61.23	$36.57	$48.43	$30.04	$55.98	$18.29	$51.27	$59.83
External costs: sum	$43.91	$29.72	$73.64	$195.47	$114.83	$41.29	$156.13	$61.38
External costs: per rider	$1.16	$0.72	$0.93	$0.95	$1.26	$3.18	$1.50	$3.41
Total social costs[16]: sum	$2,525.26	$1,651.96	$4,177.22	$7,578.57	$5,821.11	$331.15	$6,152.26	$1,200.73
Total social costs: per rider	$66.45	$40.29	$52.88	$36.79	$63.97	$25.47	$59.16	$66.71

Notes: LT – Link Transit, CT – Community Transit, KT – Kitsap Transit

Table 4-4. Estimated cost components for driving

Cost types	LT Leavenworth	LT Chelan	Total for LT areas	CT Lynnwood	KT Bainbridge Island	KT Kingston	Total for KT areas	Whidbey Island
Travelers' generalized costs: sum	$162.38	$142.04	$304.42	$996.58	$604.94	$116.39	$721.33	$152.15
Travelers' generalized costs: per rider	$4.27	$3.46	$3.85	$4.84	$6.65	$8.95	$6.94	$8.45

[16] For Metro Flex and fixed-route transit, the ride fares paid by passengers but collected by transit agencies were excluded from the total cost. The total ride fares by fixed-route transit are lower than those by Metro Flex because transit is not available for some trips in the study areas. When simulating the cost of traveling by transit, it is assumed that those trips for which transit is not available would choose to walk.

Cost types	LT Leavenworth	LT Chelan	Total for LT areas	CT Lynnwood	KT Bainbridge Island	KT Kingston	Total for KT areas	Whidbey Island
On-Street parking: sum	$37.48	$37.48	$74.96	$191.34	$61.15	$13.81	$72.98	$17.75
On-street parking: per rider	$0.99	$0.91	$0.95	$0.93	$0.67	$1.06	$0.70	$0.99
Surface parking with free land: sum	$49.58	$49.58	$99.15	$253.10	$80.89	$18.26	$96.54	$23.48
Surface parking with free land: per rider	$1.30	$1.21	$1.26	$1.23	$0.89	$1.40	$0.93	$1.30
Surface parking: sum	$59.00	$59.00	$118.01	$301.23	$96.27	$21.74	$114.90	$27.95
Surface parking: per rider	$1.55	$1.44	$1.49	$1.46	$1.06	$1.67	$1.10	$1.55
Structured parking: sum	$117.83	$117.83	$235.66	$601.56	$192.25	$43.41	$229.46	$55.81
Structured parking: per rider	$2.93	$2.72	$2.82	$2.92	$2.11	$3.34	$2.21	$3.10
External costs: sum	$36.88	$29.48	$53.37	$174.22	$121.44	$27.81	$149.25	$39.84
External costs: per rider	$0.97	$0.72	$0.68	$0.85	$1.33	$2.14	$1.44	$2.21
Total social costs without parking space: sum	$198.91	$171.24	$354.15	$1,169.35	$725.32	$143.97	$869.29	$191.61
Total social costs without parking space: per rider	$5.23	$4.18	$4.48	$5.68	$7.97	$11.07	$8.36	$10.65
Total social costs, on-street parking: sum	$236.38	$208.72	$429.10	$1,360.69	$786.47	$157.78	$942.27	$209.75
Total social costs, on-street parking: per rider	$6.22	$5.09	$5.43	$6.61	$8.64	$12.14	$9.06	$11.65
Total social costs, surface parking with free land: sum	$248.48	$220.82	$453.30	$1,422.45	$806.21	$162.23	$965.83	$215.48
Total social costs, surface parking with free land: per rider	$6.54	$5.39	$5.74	$6.91	$8.86	$12.48	$9.29	$11.97
Total social costs, surface parking: sum	$257.91	$230.25	$472.15	$1,470.58	$821.59	$165.71	$965.83	$215.48

Cost types	LT Leavenworth	LT Chelan	Total for LT areas	CT Lynnwood	KT Bainbridge Island	KT Kingston	Total for KT areas	Whidbey Island
Total social costs, surface parking: per rider	$6.79	$5.62	$5.98	$7.14	$9.03	$12.75	$9.46	$12.22
Total social costs, structured parking: sum	$316.74	$289.07	$589.81	$1,770.91	$917.57	$187.38	$1,098.75	$247.81
Total social costs, structured parking: per rider	$8.34	$7.05	$7.47	$8.60	$10.08	$14.41	$10.56	$13.77

Notes: LT – Link Transit, CT – Community Transit, KT – Kitsap Transit

Table 4-5. Estimated cost components for transit

Cost types	LT Leavenworth	LT Chelan	Total for LT areas	CT Lynnwood	KT Bainbridge Island	KT Kingston	Total for KT areas	Whidbey Island
Travelers' generalized costs: sum	$740.21	$476.88	$1,217.09	$3,082.31	$2,967.10	$507.53	$3,474.64	$600.09
Travelers' generalized costs: per rider	$19.48	$11.63	$15.41	$14.96	$32.61	$39.04	$33.41	$33.34
Daily operating costs[17]: sum	$397.15	$503.10	$900.25	$1,126.73	$7,348.29	$1,522.35	$8,870.64	$556.29
Daily operating costs: per rider	$10.45	$12.27	$11.40	$5.47	$80.75	$117.10	$85.29	$30.91
External costs sum	$0.13	$0.40	$0.53	$29.98	$18.99	$1.73	$20.73	$5.43
External costs per rider	$0.003	$0.01	$0.01	$0.15	$0.21	$0.13	$0.20	$0.30
Health savings: sum	$87.46	$50.48	$137.94	$163.91	$157.15	$41.24	$198.38	$57.27
Health savings: per rider	$2.30	$1.23	$1.75	$0.80	$1.73	$3.17	$1.91	$3.18
Total social costs[18]: sum	$1,070.21	$941.55	$2,011.76	$3,825.43	$10,137.50	$1,980.38	$12,117.88	$1,117.76
Total social costs: per rider	$28.16	$22.96	$25.47	$18.57	$111.40	$152.34	$116.52	$62.10

Notes: LT – Link Transit, CT – Community Transit, KT – Kitsap Transit

[17] The daily operating costs per rider for the case areas served by Kitsap Transit and Island Transit are very high according to their data. This is probably because these areas have long transit service hours despite low ridership.

[18] For Metro Flex and fixed-route transit, the ride fares paid by passengers but collected by transit agencies were excluded from the total cost. The total ride fares by fixed-route transit are lower than those by Metro Flex because transit is not available for some trips in the study areas. When simulating the cost of traveling by transit, it is assumed that those trips for which transit is not available would choose to walk.

Table 4-6. Estimated cost components for transportation network companies (TNCs)

Cost types	LT Leavenworth	LT Chelan	Total for LT areas	CT Lynnwood	KT Bainbridge Island	KT Kingston	Total for KT areas	Whidbey Island
Travelers' generalized costs: sum	$512.31	$446.49	$958.80	$1,958.92	$922.95	$199.53	$1,122.48	$354.15
Travelers' generalized costs: per rider	$13.48	$10.89	$12.14	$9.51	$10.14	$15.35	$10.79	$19.67
External costs: sum	$46.77	$33.34	$80.11	$216.23	$152.11	$34.84	$186.96	$50.70
External costs: per rider	$1.23	$0.81	$1.01	$1.05	$1.67	$2.68	$1.80	$2.82
Total social costs: sum	$559.08	$479.83	$1,038.91	$2,175.15	$1,075.06	$234.38	$1,309.44	$404.85
Total social costs: per rider	$14.71	$11.70	$13.15	$10.56	$11.81	$18.03	$12.59	$22.49

Notes: LT – Link Transit, CT – Community Transit, KT – Kitsap Transit

Figure 4-2 visualizes the stacked costs per rider of traveler, service provider, and externalities by mode across different areas. For TIMOD, the service provider's cost contributes the most to its total social cost for all the areas. Among the study cases, Leavenworth, Bainbridge Island, and Whidbey Island incur higher TIMOD operating costs per rider, due to higher hourly operating expenses and/or longer service hours deployed to serve a small group of riders. For the operating cost per rider by fixed-route transit, Bainbridge Island and Kingston have significantly higher costs due to the substantially longer total service hours allocated.

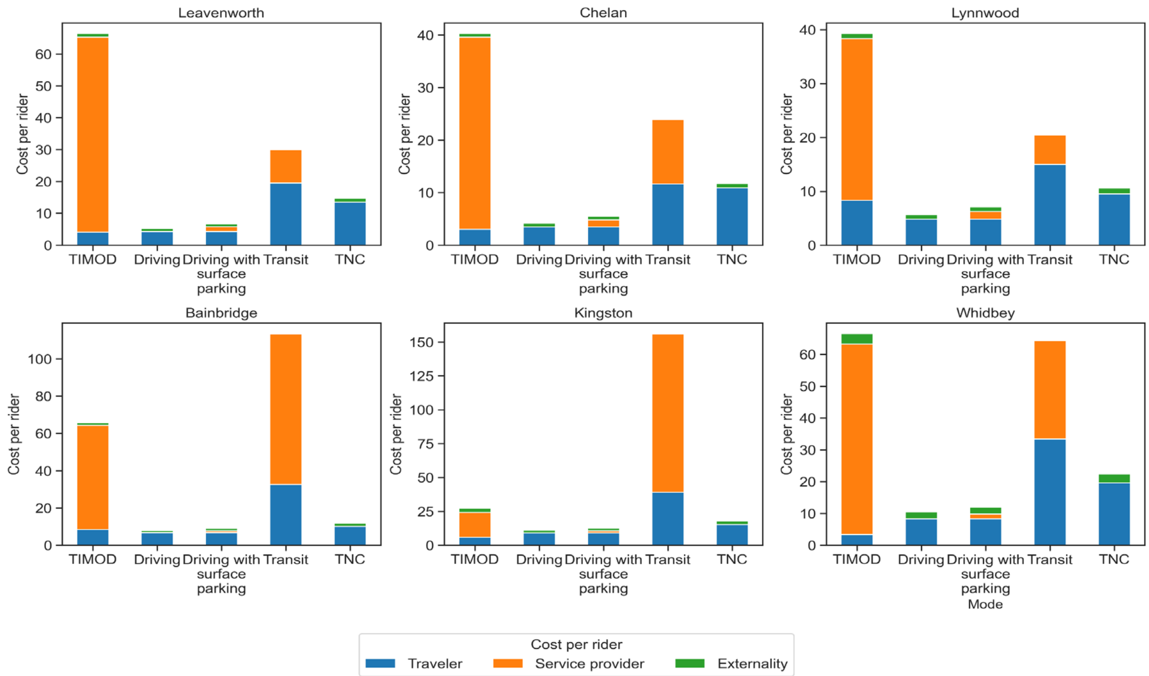

Figure 4-2. Traveler, service provider, and external costs per rider by mode and area

For the traveler's generalized cost per rider by TIMOD and driving, Leavenworth, Chelan, and Whidbey Island have lower costs than other areas because of the lower hourly wage rate and the free ride. Bainbridge Island exhibits higher generalized costs for TIMOD riders than the other cases, primarily due to longer average waiting times. Moreover, in terms of the traveler's generalized cost per rider by fixed-route transit, Bainbridge Island, Kingston, and Whidbey Island present higher costs induced by the longer trip times. Additionally, Kingston and Whidbey Island have the highest generalized costs for a TNC rider, which is caused by the longer wait times associated with TNC services.

With regard to the external cost per rider, Chelan has the lowest cost for TIMOD due to the more common shared rides. Lynnwood also has a relatively low external cost per rider for TIMOD because of the shorter trips. Whidbey Island has a relatively higher external cost per rider than other areas due to its longer trip distance on average. For the external cost per rider by fixed-route transit and TNC, Bainbridge Island, Kingston, and Whidbey Island have relatively higher costs than others due to the longer trips. Due to the shared rides, TIMOD induces smaller external costs than TNCs in most cases except for Kingston and Whidbey Island.

4.3 Sensitivity Analysis

Figure 4-3 presents the total social cost by mode and area as changes in hourly wage. Driving, even with considering the cost of constructing and maintaining parking spaces, remains the most cost-effective option across all hourly wage levels in each area. When serving higher-income groups, the comparative cost disadvantage of TIMOD becomes smaller compared to fixed route transit. This is due to the demand-responsive nature of TIMOD service, which results in time savings. In Leavenworth, Chelan, and Lynnwood, TIMOD remains the highest-cost option across all wage percentiles. Additionally, the results suggest that both TIMOD and fixed-route transit are more sensitive to changes in the traveler's value of time, largely due to longer waiting times.

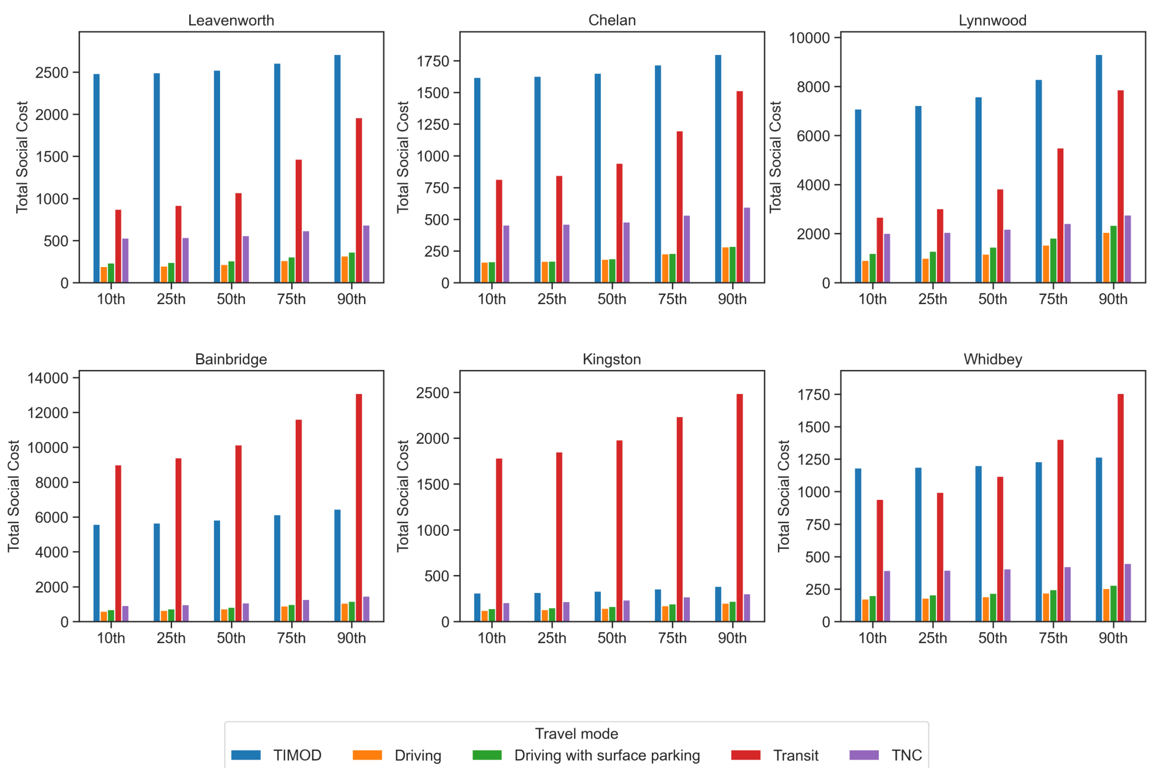

Figure 4-3. Total social cost on a typical weekday by changes in hourly wage

Figure 4-4 illustrates how the comparative cost-effectiveness of TIMOD changes with reductions in its hourly operating costs. Among the study areas, Leavenworth and Lynnwood require an 80 percent reduction in TIMOD’s hourly operating cost for its total social cost to fall below that of fixed-route transit. However, even with an 80 percent reduction, TIMOD's total social cost in these two areas remains higher than that of TNCs. In Chelan, TIMOD's hourly operating cost must be reduced by 60 percent to be more cost-effective than fixed-route transit, and by 80 percent to be lower than TNCs. In Bainbridge Island, TIMOD's total social cost is higher than that of TNCs even with an 80 percent reduction. In Kingston, TIMOD can be more cost-effective than TNCs with a 60 percent reduction. In Whidbey Island, TIMOD's hourly operating cost must be reduced by 20 percent to be more cost-effective than fixed-route transit, and by 80 percent to be lower than TNCs.

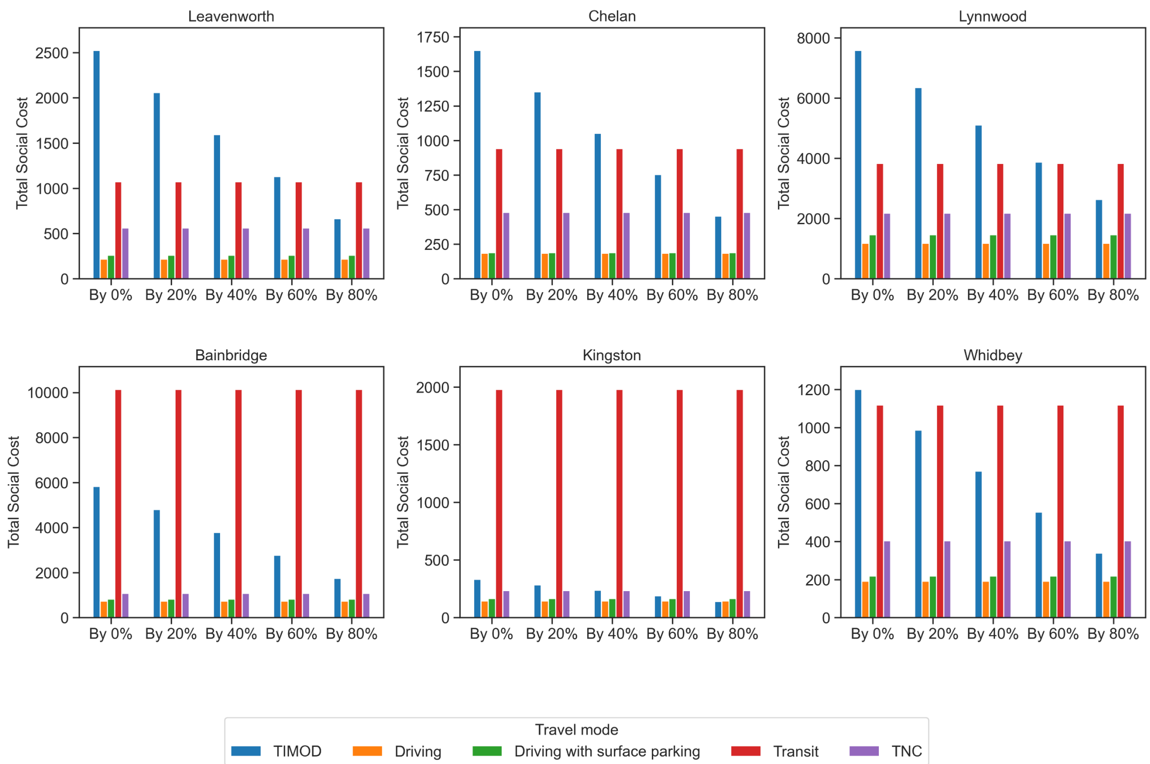

Figure 4-4. Total social cost on a typical weekday by changes in TIMOD hourly operating cost

Figure 4-5 illustrates how the comparative cost-effectiveness of mobility alternatives changes as the cost of transit waiting time decreases. As shown, reducing waiting time, and thus its associated cost, does not alter the comparative cost-effectiveness of different modes in the case areas. The cost of waiting time accounts for only a small portion of total travel time and makes a minor contribution to the social cost of fixed-route transit for these areas. Actually, waiting time is not even applicable to some trips when fixed-route service is unavailable. In such cases, travelers would spend significantly more time walking rather than using fixed-route transit service.

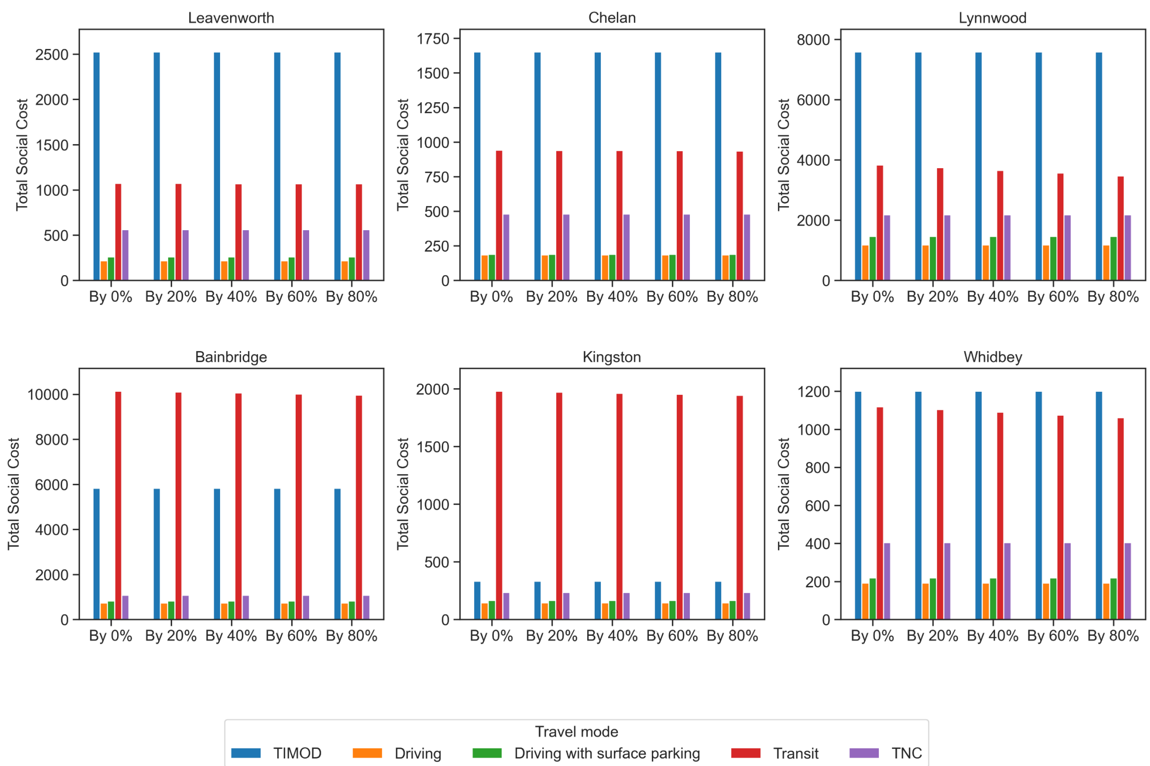

Figure 4-5. Total social cost on a typical weekday by changes in transit waiting time cost

5 Discussion

5.1 Economic Costs of TIMOD Compared to Other Alternatives

Compared to fixed-route transit, TIMOD has the advantage of saving travelers' time due to its demand-responsive nature, which is similar to the findings of the previous study (Wang and Shen, 2023; Cai, et al., 2025). As a tradeoff, the operating cost per rider is higher for TIMOD than for fixed-route transit in some, but not all areas. This higher cost of TIMOD stems from the extended daily vehicle hours deployed to sustain personalized point-to-point service. This contrasts with the findings of Wang and Shen (2023), where the service was structured as point-to-station (i.e., first mile/last mile for light rail transit riders) with a comparable number of daily trips. From a societal perspective, the comparative cost-effectiveness of TIMOD and fixed-route transit can be significantly affected by how transit agencies plan and deploy the services. The results do not show an obvious association between population density and the comparative cost-effectiveness of these two travel modes.

Compared to TNCs, TIMOD offers subsidized fares to riders, benefiting them through trip fare savings. Meanwhile, TIMOD has slightly lower external costs than TNCs due to the higher proportion of shared rides and the resulting reduction in vehicle miles traveled. The external costs of TIMOD, particularly the costs of crashes and congestion, could be further reduced if it can use existing bus lanes. Nevertheless, TIMOD is more sensitive to changes in travelers' value of time than TNCs, owing to its longer travel time resulting from detours for shared rides and longer waiting time.

Driving is shown to be the most cost-effective mode in the study areas, even considering the costs of additional parking spaces. This finding is consistent with Blumenberg et al. (2024)'s argument that policymakers should consider offsetting the costs of car ownership and access for disadvantaged groups. The comparative cost advantage of driving may be less pronounced in densely populated areas, where heavy traffic and induced congestion can lead to higher time costs and higher external costs for society. Cost advantages associated with driving could also be reduced if purchase price and vehicle type is factored into traveler's cost. The methodology assumes that the traveler has access to a vehicle and utilizes a common passenger car (Toyota Camry).

The findings of this study indicate that in low-density areas, TNCs are more cost-effective than TIMOD from a societal perspective. However, prior research has shown that TNCs' profit-driven model restricts service coverage in some suburban areas with low demand (Barajas and Brown, 2021). Additionally, its high fares and surge prices further limit service accessibility for disadvantaged groups (Bardaka et al., 2020). Given the comparative advantages and limitations of TIMOD and TNCs, transit agencies should explore subsidized TNC service as a mobility alternative to satisfy the travel needs of disadvantaged populations in low-density areas.

In these study areas, where the density of transit service is relatively low, TIMOD demonstrates a pronounced advantage over fixed-route transit in terms of traveler's generalized cost. For example, in Leavenworth and Chelan, the generalized cost per rider of TIMOD is 21 percent and 26 percent of that of fixed-route transit in these two areas, respectively. However, the operating cost per rider for TIMOD is nearly 600 percent and 300 percent of that of fixed-route transit in these two areas, respectively. In Lynnwood, where the density of transit service is relatively high, the generalized cost for riders of TIMOD is 55% of that for fixed-route transit in the area. However, the operating cost per rider for TIMOD is nearly 550% of that of fixed-route transit in this area. This suggests that whether TIMOD can be a more cost-effective alternative for travelers than fixed-route transit depends on the context and the trade-offs between traveler benefits and service provider costs.

The cost-effectiveness of a transportation mode is sensitive to the assumptions made in this study. For instance, the operating costs of service providers could be lower if autonomous electric vehicles were widely adopted. The costs of service operation and the environmental externalities could be affected by savings from drivers' wages and cleaner technologies, which may lead to different findings (Bösch, et al., 2018). This may offer a more cost-effective solution to reduce labor cost when serving sparse mobility demand in low-density areas where daily vehicle usage rates are low. Additionally, future evaluations of TIMOD operating costs should account for the potential increase in demand driven by greater market penetration. This heightened demand could enhance the economies of scale for TIMOD services.

5.2 Social Inclusion Benefits of TIMOD

While the economic analysis highlights the trade-offs of TIMOD, this section shifts the discussion toward social inclusion, recognizing that cost-inefficiency in fiscal terms does not equate to inefficiency in societal value. Despite TIMOD's higher operating costs relative to other modes, it provides disproportionate benefits for vulnerable and mobility-constrained populations—benefits that are not easily offset by financial deficits.

TIMOD's relatively higher monetary costs can be justified by its targeted subsidies and point-to-point design, which deliver accessibility to populations underserved by fixed-route systems. Analysis of user composition across the Link Transit systems in Chelan and Leavenworth and the Zip Shuttle in Lynnwood underscores this inclusivity dimension. Appendix A summarizes the aggregated results of user profiles and riding experiences. Compared with the citywide population, both TIMOD and fixed-route transit riders are disproportionately drawn from groups facing structural barriers to mobility, suggesting that public transit functions as more than a mobility service—it acts as essential social infrastructure for equity.

Demographically, the rider base skews toward age groups often challenged in mobility: over 12% of riders in Chelan are 65 or older, while 15% in Leavenworth and 21.5% in Lynnwood are under 18. Racial and ethnic patterns also differ sharply from city averages, with more than half of riders identifying as non-white and nearly one-third as Hispanic/Latino. In Lynnwood, about 32.5% of Zip Shuttle users report having at least one type of disability, highlighting the system's critical role in addressing accessibility gaps. Meanwhile, socioeconomic disparities among users are even more striking. Between one-quarter and one-third of riders live in households earning below $15,000 annually. In Lynnwood, at least 32.8% of Zip users fall into the "extremely low-income" category, and over half earn less than half of the regional median income. Only about one-third are employed full-time, while many are unemployed. These findings confirm that microtransit systems like TIMOD primarily serve individuals least able to afford private alternatives, underscoring the equity consequences of fare increases or service reductions. From an equity perspective, this means that service cuts or fare increases would impose disproportionate burdens on the most disadvantaged, while targeted improvements in affordability, coverage, and reliability would directly enhance inclusion and resilience.

Accessibility indicators reinforce this inclusion argument related to TIMOD or transit riders. A significant share of households using transit lack access to private vehicles—28% in Leavenworth and nearly 18% in Chelan. Even among households with cars, transit substitutes for 18% to 29% of driving-alone trips, demonstrating that it is not only a safety net for the carless but also a viable alternative to automobile dependence. Most critically, a substantial portion of trips, about one-quarter in Leavenworth and one-sixth in Chelan, are reported as "urgent," meaning they would not have occurred without transit. These urgent trips likely represent access to employment, healthcare, or other essential needs, highlighting the indispensable role of transit in safeguarding basic mobility for the disadvantaged people in low-density suburban and rural communities.

In sum, these findings indicate that while TIMOD may appear less cost-effective in economic terms, its social inclusion and equity benefits are substantial. By connecting disadvantaged populations to opportunities and essential services, TIMOD mitigates social exclusion, enhances equitable access, and strengthens community resilience. In this sense, expanding and integrating TIMOD within suburban transit networks represents a strategic shift from an efficiency-oriented planning paradigm to one that equally values fairness, participation, and inclusive growth.

6 Conclusions and Policy Implications

This study further developed a framework to compare the cost-effectiveness of TIMOD to three alternative modes – fixed-route public transit services, driving, and TNCs – using real-world TIMOD trip data. The study addressed questions related to the factors determining the comparative cost-effectiveness of TIMOD and other transportation options, measured and compared the social costs across different types of mobility services, and explored the conditions and arrangements under which TIMOD services can become more cost-effective in low-density areas. While the selected case areas are considered as low-density suburban and rural areas, they have distinct transit service provisions, built environments, and sociodemographic characteristics. The findings of this study provide an empirical basis for evaluating the economic costs of TIMOD in addressing the mobility needs of a segment of disadvantaged population in suburban and rural areas currently relying on this service.

The fares for riding TIMOD and fixed route service are as follows, and are affected by transportation legislation, such as Move Ahead Washington and associated youth fare-free programs. Island Transit's GO! service is a fare-free service for all riders. Community Transit's Zip Shuttle costs $2.50 to ride but offers fare-free service for riders under 18. Riders carrying an ORCA Lift card have a reduced fare of $1.00. ORCA Lift Card is a reduced-fare program offered to eligible riders meeting the income criteria. Income must be no more than 200 percent of the Federal Poverty level, as established by the U.S. Health and Human Services Department. Those receiving Apple Health Medicaid, WIC and Basic Food are eligible for the program. Link Transit's DART service is a fare-free service for all riders.

Most of the funding for these transit agencies comes from locally generated sales taxes. TIMOD can be directly operated or purchased through a vendor, and can be funded through a mix of local, federal and state funding sources. The type of funding with specific conditions are the federal and state sources – primarily focused on specific place types, recipients and activities.

1) 5307 – Urbanized Area Formula Grants (pop 50,000 or more): The Urbanized Area Formula grant program provides funding for transit capital and operating assistance and transportation-related planning in urbanized areas (50,000 or more). 5307 funding can be used for capital and operating expenses for ADA paratransit service, but is not used for TIMOD.

2) 5310 – Enhanced Mobility of Seniors and Individuals with Disabilities (all population sizes): This program provides formula funding to states and designated recipients to meet the transportation needs of older adults and people with disabilities when the transportation service provided is unavailable, insufficient, or inappropriate to meet these needs. Funding for this program is primarily for ADA paratransit, but can be used for certain TIMOD expenses.
3) 5311 – Formula Grants for Rural Areas (pop 50,000 or less): This grant program provides capital, planning, and operating assistance to support public transportation in rural areas with populations less than 50,000. This funding source is commonly used for TIMOD.

The study extended a conceptual framework for measuring the marginal economic cost of a mobility option, taking into account service provider costs, user monetary and time costs, and transportation externalities. The results revealed various insights into the cost-effectiveness of different modes of transportation. Driving emerged as the economically lowest-cost option for society, while TIMOD, as a demand-responsive mobility service with subsidized fares, demonstrated a competitive cost advantage over fixed-route transit and TNCs from a traveler's perspective. Driving has the lowest marginal social cost in the suburban areas, but this mobility option may not be available to those who are financially or health disadvantaged.

Given that the marginal costs to society are shown to be lower for driving and riding TNC in the study cases, transit agencies should explore alternative ways to improve mobility for disadvantaged suburban and rural residents by offsetting costs for driving and subsidizing fares for riding TNCs. On the other hand, we are aware of the concerns about service availability and the varying waiting time of TNCs in suburban areas as discussed above, which may raise the question about whether TNCs are more cost-effective than TIMOD across all suburban areas. Another consideration is that the operating cost of TIMOD is sensitive to the level of demand, which can be substantially higher in certain denser suburban locations. This potential economy of scale may also affect the comparative cost-effectiveness of TIMOD in comparison to TNCs.

The study also highlighted that the operating cost of TIMOD per rider can be much higher than that of fixed-route transit in some cases, indicating that TIMOD's service deployment and operating model need improvements to be more financially sound. Additionally, the study shed light on the importance of accounting for externalities, including air pollution, greenhouse gas emissions, crashes, congestion, and noise. Although these estimated external costs are relatively minor compared to other cost components, they are not negligible and could become more prominent in the future, particularly due to the growing threat of climate change. TIMOD services such as those studied in this project have demonstrated a slight reduction in external costs compared to TNCs, attributable to more common pooling of multiple riders in TIMOD services. These cost factors should be included in the framework of cost-effectiveness analysis.

The selected case areas have different built environments and sociodemographic characteristics, resulting in different estimated costs. Compared to transit riders, travelers in areas with lower transit service density experience greater cost benefits from using TIMOD due to a more substantial reduction in time costs. Such differences should be informative for transit agencies seeking to improve their TIMOD programs by considering the tradeoffs between travelers' benefits and service provider's costs.

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APPENDIX A

Beyond economic analysis of TIMOD based on trip data, this study also examines data on user profiles and riding experiences. First, using the 2023 Link Transit Survey data from Social and Economic Sciences Research Center at Washington State University as supplementary information for users' profile, this study analyzes the basic demographic and socioeconomic characteristics of Link Transit users in Leavenworth and Chelan cities. The user profiles in the study area are based on 129 valid survey responses collected from riders on four fixed-route bus lines (Routes 21 and 22, Leavenworth DART, and Chelan DART). Second, for specific user riding experiences, this study analyzes the 2025 pilot survey data of Zip Shuttle – an on-demand shared ride service for Alderwood in Lynnwood, to represent the rider compositions. The services are operated by Community Transit for some communities in Snohomish County. In total, the survey collects answers to nine questions from 815 respondents.

Figure A-1. Demographic and socioeconomic characteristics of Link Transit users in Leavenworth and Chelan

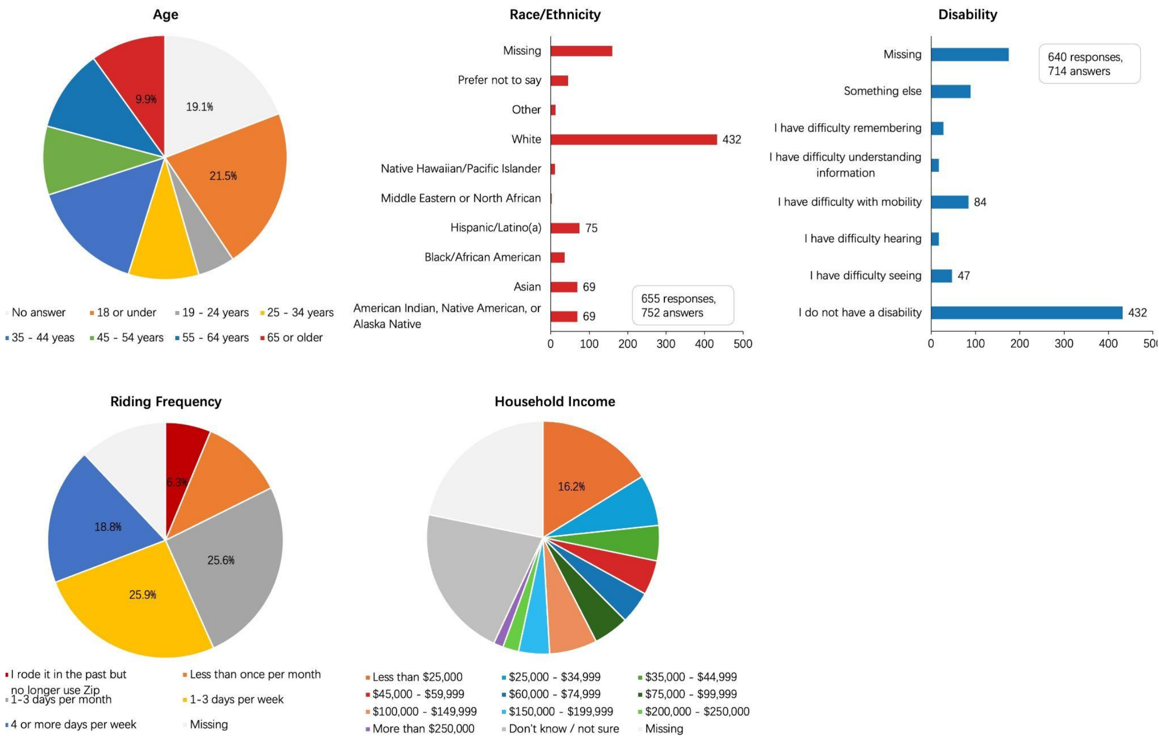

Figure A-2. Demographic and socioeconomic characteristics of Zip Shuttle users in Lynnwood

Table A-1. Income distribution of Link Transit users in Leavenworth and Chelan by household size

Income	No answer	1	2	3	4+
Leavenworth City: No answer	2.00%	2.00%	4.00%	2.00%	6.00%
Leavenworth City: Under $15,000	-	18.00%	2.00%	6.00%	8.00%
Leavenworth City: $15,001 - $25,000	-	2.00%	2.00%	-	4.00%
Leavenworth City: $25,001 - $35,000	-	-	6.00%	2.00%	8.00%
Leavenworth City: $35,001 - $50,000	-	6.00%	2.00%	-	2.00%
Leavenworth City: $50,001 - $75,000	-	-	2.00%	-	-
Leavenworth City: More than $75,000	-	-	6.00%	4.00%	4.00%
Chelan City: No answer	2.50%	-	1.30%	2.50%	2.50%
Chelan City: Under $15,000	5.10%	10.10%	2.50%	3.80%	3.80%
Chelan City: $15,001 - $25,000	-	6.30%	2.50%	1.30%	1.30%
Chelan City: $25,001 - $35,000	-	1.30%	3.80%	5.10%	3.80%
Chelan City: $35,001 - $50,000	-	1.30%	3.80%	1.30%	3.80%
Chelan City: $50,001 - $75,000	-	-	5.10%	-	7.60%
Chelan City: More than $75,000	-	2.50%	5.10%	2.50%	7.60%
MSA-level income limits Extremely Low Income (30%)	-	17,750	20,250	22,800	25,300
MSA-level income limits Very Low Income (50%)	-	29,550	33,750	37,950	42,150
MSA-level income limits	-	47,250	54,000	60,750	67,450

Income	No answer	1	2	3	4+
Low Income (80%)					

Notes: Income was in 2023. Income limits are based on standards adopted from 2023 Adjusted HOME Income Limits for Washington State, U.S. Dept. of HUD

Table A-2. Income distribution for Zip Shuttle users in Lynnwood by household size

Income	1	2	3	4	5	6	7	8+	Sum
Less than $25,000	7.78%	4.54%	4.75%	4.75%	2.81%	1.3%	0.86%	1.51%	28.29%
$25,000 - $34,999	3.46%	4.54%	0.65%	1.73%	0.86%	1.08%	-	0.22%	12.53%
$35,000 - $44,999	1.30%	1.94%	1.73%	1.94%	1.08%	0.22%	-	0.43%	8.64%
$45,000 - $59,999	1.51%	1.94%	1.3%	0.86%	1.94%	0.43%	0.22%	0.22%	8.42%
$60,000 - $74,999	0.86%	2.16%	1.3%	1.08%	1.94%	-	0.65%	-	7.99%
$75,000 - $99,999	0.86%	1.73%	0.65%	1.51%	2.16%	1.3%	0.43%	-	8.64%
$100,000 - $149,999	0.65%	2.38%	2.59%	2.81%	1.51%	1.08%	0.65%	-	11.66%
$150,000 - $199,999	0.43%	1.94%	1.73%	2.16%	0.86%	0.43%	-	-	7.56%
$200,000 - $250,000	-	1.3%	1.08%	0.86%	0.22%	0.43%	-	-	3.89%
More than $250,000	-	0.65%	0	0.65%	0.43%	0.22%	0.43%	-	2.38%
Sum	16.85%	23.11%	15.77%	18.36%	13.82%	6.48%	3.24%	2.38%	100%
MSA: Extremely Low Income (30%)	27,200	31,050	34,950	38,800	41,950	45,050	48,150	51,250	-
MSA: Very Low Income (50%)	45,300	51,800	58,250	64,700	69,900	75,100	80,250	85,450	-
MSA: Low Income (80%)	66,750	76,250	85,800	95,300	102,950	110,550	118,200	125,800	-

Notes: MSA = MSA-level income limits
Income was in 2022 before taxes. Income limits are based on standards adopted from 2022 Adjusted HOME Income Limits for Washington State, U.S. Dept. of HUD.

Table A-3. Alternative travel mode by vehicle ownership if Link Transit does not exist

Mode	No answer	0 (no cars)	1 car	2 cars	3 cars or more
Leavenworth City Multiple answer	-	6.00%	2.00%	2.00%	-
Leavenworth City No answer	6.00%	-	2.00%	-	-
Leavenworth City Drive alone	-	2.00%	2.00%	6.00%	10.00%
Leavenworth City Get a ride or carpool	-	6.00%	14.00%	6.00%	2.00%
Leavenworth City Taxi/Uber/Lyft	-	-	-	-	-
Leavenworth City Bike/Scooter	-	2.00%	-	-	-
Leavenworth City Walk	-	2.00%	-	2.00%	4.00%
Leavenworth City Would not have made this trip	4.00%	10.00%	6.00%	4.00%	-

Mode	No answer	0 (no cars)	1 car	2 cars	3 cars or more
Leavenworth City Other	-	-	-	-	-
Chelan City Multiple answer	-	1.30%	2.50%	1.30%	2.50%
Chelan City No answer	2.50%	-	3.80%	1.30%	1.30%
Chelan City Drive alone	-	-	10.10%	15.20%	3.80%
Chelan City Get a ride or carpool	1.30%	5.10%	5.10%	3.80%	3.80%
Chelan City Taxi/Uber/Lyft	-	-	2.50%	-	-
Chelan City Bike/Scooter	-	1.30%	-	-	1.30%
Chelan City Walk	-	2.50%	2.50%	2.50%	2.50%
Chelan City Would not have made this trip	-	7.60%	3.80%	1.30%	3.80%
Chelan City Other	-	-	1.30%	2.50%	-

Table A-4. Summary of sociodemographic characteristics of users of Link Transit and Zip Shuttle

Sociodemographic characteristics	Population Leavenworth City	Population Chelan City	Population Lynnwood City	Link Transit Leavenworth City	Link Transit Chelan City	Zip Shuttle Lynnwood City
Median hourly wage	\$23.04	\$23.04	\$32.46	-	-	-
Population density (sq. mi)	1,841	644	5,199	-	-	-
Median age	42.3	46.7	39.2	-	-	-
Ratio of bachelor's degree or higher	45.6%	26.5%	32.6%	-	-	-
Median household income (\$)	\$74,653	\$71,996	\$76,439	-	-	-

Table A-5. Summary of vulnerable users of Link Transit and Zip Shuttle

Vulnerable groups	Population Leavenworth City	Population Chelan City	Population Lynnwood City	Link Transit Leavenworth City	Link Transit Chelan City	Zip Shuttle Lynnwood City
18 or under	22%	17%	19%	≥10%	≥15.2%	≥21.5%
65 or above	18%	27%	18%	≥12%	≥15.2%	≥9.9%
Non-white	12%	25%	49%	54%	57%	34%
Disability	13.25%	16.24%	15.3%	-	-	32.5%
Below poverty line	6.2%	9.5%	14.2%	34% (≤15K)	25.3% (≤15K)	16.2% (≤25K)
No vehicle available	12.6%	1%	12.7%	28%	17.7%	-

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