

**SUPPLEMENTING FIXED-ROUTE TRANSIT WITH  
DYNAMIC SHARED MOBILITY SERVICES: A  
MARGINAL COST COMPARISON APPROACH**  
FINAL PROJECT REPORT

by

Qing Shen<sup>a</sup>, Yiyuan Wang<sup>a</sup>, Casey Gifford<sup>b</sup>

<sup>a</sup>University of Washington

<sup>b</sup>King County Metro Transit

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More Hall 112, Box 352700

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## SI\* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
<b>TEMPERATURE (exact degrees)</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela/m <sup>2</sup>	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in <sup>2</sup>

\*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.  
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## EXECUTIVE SUMMARY

### General Background

In the era of app-based shared mobility, more and more transit agencies have started to explore the incorporation of app-based shared mobility into their services to fill in the gaps of existing fixed-route transit. Although the cost-effectiveness of offering shared mobility over expanding traditional transit is often used to justify the implementation of such pilots, major gaps remain for transit agencies to both appropriately understand and empirically estimate the costs of different options, and such gaps could lead to misunderstanding regarding which service option has true cost advantages.

### Problem Statement

This study was an attempt to fill this knowledge gap by answering three questions:

- What are the conceptual differences between the marginal cost and the average cost of providing mobility service? What are the major components of the marginal costs?
- How do marginal costs differ among traditional transit service expansion (in this study, increasing bus frequencies on existing routes), providing on-demand services, and providing park and ride facilities?
- How can public transit agencies empirically estimate and compare the marginal costs of different options using rigorous data-based approaches?

### Methodology

This study addressed the questions above with two methodological components. First, we developed a theoretical framework based on the economic concept of marginal cost that we believe provides more pertinent information for decision-making about different service provision options. Second, the study built a transportation simulation procedure that allows

transit agencies to empirically compare the marginal cost of incorporating app-based shared mobility with the marginal cost of expanding traditional service and the cost of providing park and ride facilities. Applying this approach to the case of Via to Transit, a mobility pilot in the Seattle region, the study demonstrated how the results can be used to effectively evaluate the outcome of incorporating app-based shared mobility into transit service provision and to inform future decision-making.

### Major Findings and Their Implications

- Findings

Based on the theoretical framework and the simulation model, the total marginal economic costs were obtained for comparing Via to Transit with traditional fixed-route expansion and park and ride facilities, and the results help clarify misunderstandings in previous literature. The results also fully demonstrated the cost-advantages of incorporating on-demand shared modes in areas where running fixed-route transit is costly.

- Impact on Future Research and Practice

This study addressed a critical yet understudied topic in current transportation planning and policy-making practice. The theoretical framework and the simulation model have great practical value for the public transportation sector within and beyond the Pacific Northwest, as many transit agencies are exploring non-traditional ways to maintain and improve transit services. The approach developed in the report can be directly adopted by transit agencies to determine, contextually, whether engagement with shared mobility service providers will, indeed, be cost effective.

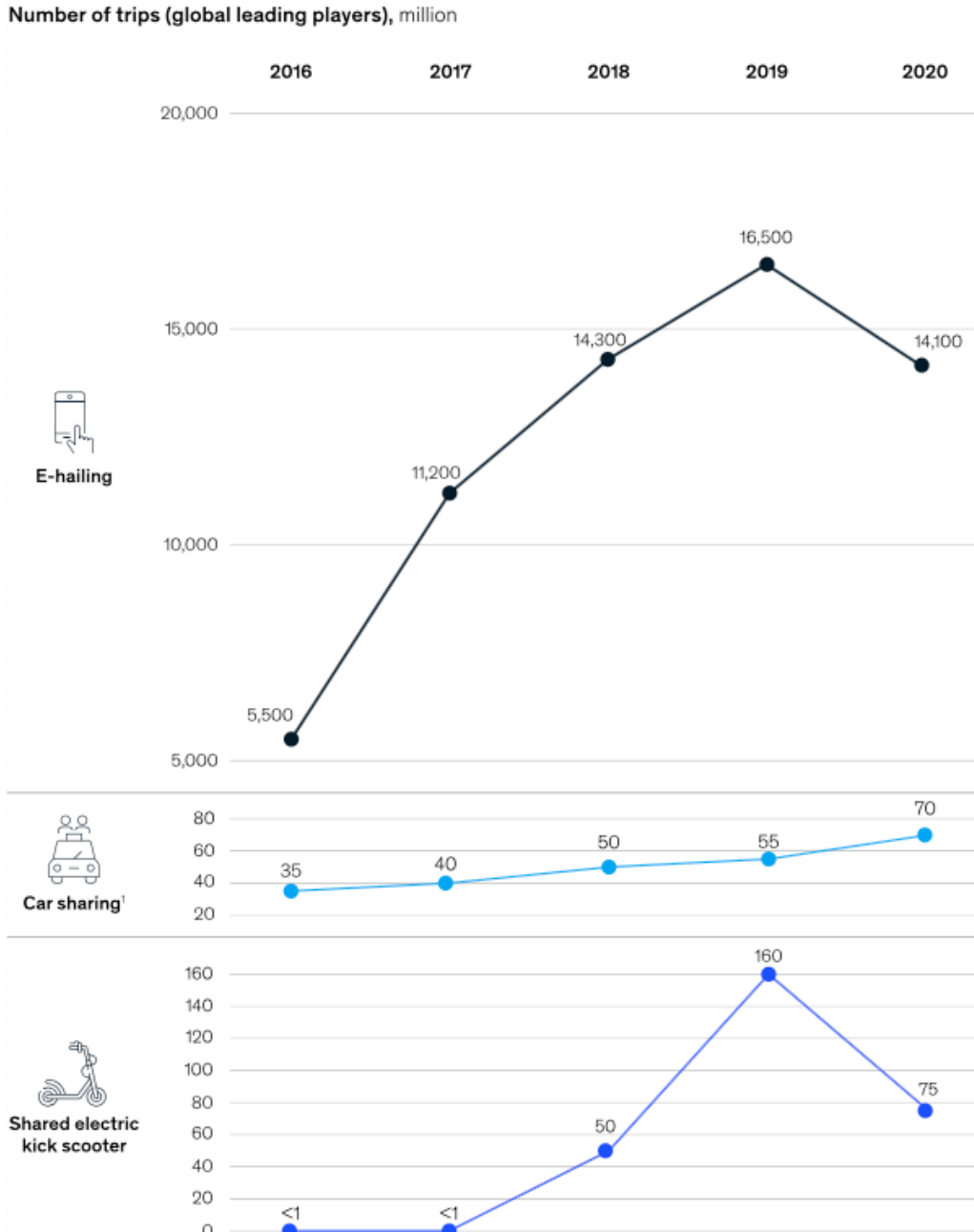
## CHAPTER 1. BACKGROUND

### 1.1. The Emergence and Growth of App-Based Shared Mobility

App-based mobility sharing, in the forms of ride-hailing, ride-splitting, car-sharing, bike-sharing, micro-transit, scooter-sharing, etc., has shown phenomenal growth since the 2010s. In comparison to traditional mobility sharing (e.g., transit, taxi, and family- or social network-based carpooling) that has existed in cities for a long time, such new shared mobility services have several distinctive characteristics:

- They typically draw from a large pool of users, unconfined by one's social network;
- They allow for real-time mobility matching and sharing;
- They rely on the ubiquitous use of smartphone apps and mobile information and communication technologies (Mobile-ICTs);
- They employ algorithms for service operation and thus are capable of achieving high efficiency; and
- They are typically owned by profit-driven private companies and thus often operate beyond the realms of public transit and transportation planning (Gössling, 2018; Moudon, 2020).

Recent estimates (as shown in figure 1.1) have shown that, globally, the trip bookings of ride-hailing, the most common form of app-based shared mobility, tripled from 2016 to 2019, and trip bookings from major platforms per day surpassed 40 million. Use of another quickly emerging form, scooter-sharing, doubled from 2018 to 2019 (Heineke et al., 2021). Similar trends were observed in recent survey data obtained in the Seattle region as well (Wang et al., 2021), where the use of ride-hailing grew substantially from 2012 to 2018.



**Figure 1.1** Estimated number of trips for selected shared mobility modes  
 Source: Heineke et al. (2021)

1.2. Integrating App-Based Shared Mobility Modes into Public Transit

These new services are expected to offer great convenience to users by allowing them to travel through mobility sharing, which is of particular importance to those who do not have access to private vehicles. In addition to directly benefiting individual users, transportation

researchers and practitioners have recognized that shared mobility also generates broader societal benefits by complementing traditional public transit.

Historically, the automobile has always been the most common, and often the only, travel option for people in the U.S. (Manville et al., 2017), while public transit has long struggled to provide an adequate level of service (Watkins et al., 2019). In addition, the urban expansion and decentralization facilitated by telecommunications have been a long-lasting trend in the US (Mokhtarian, 2000; Shen, 2000). More recently, the widely adopted movement to work from home since the COVID-19 pandemic began is likely to further accelerate such a trend (Florida et al., 2021). The resulting decline in demand density for public transit, coupled with a growing emphasis on transportation equity, further challenges transit agencies' capacity (Tirachini and Cats, 2020).

Multiple reports have been published by the U.S. Department of Transportation (DOT) calling for greater integration between public transit and app-based mobility services (Feigon and Murphy, 2016; McCoy et al., 2018). In addition, the Federal Transit Administration has directly funded eleven Mobility on Demand (MOD) Sandbox projects since 2016, many of which have explored the integration of shared mobility services to supplement existing transit. Table 1.1 summarizes typical examples of such partnerships between transit agencies and mobility service providers. These innovations include utilizing app-based shared mobility as first-mile/last-mile solutions, guaranteed ride home options, or even replacements to some low-efficiency transit services (see the Service to provide column in table 2.1). In this report, we use the term Transit Incorporating Mobility on Demand (TIMOD) to be consistent with the name used by the federal DOT and to accurately capture the supplementary roles played by shared mobility services in enhancing public transit. Similar terminologies, including multimodal integrations, innovative

mobility programs, shared mobility public-private partnerships (King County Metro, 2022; Wang et al., 2022), have appeared in the literature, each with a somewhat different emphasis.

**Table 1.1** Summary of transit agencies’ pilot partnerships with app-based shared mobility service providers

<b>Project name</b>	<b>Region</b>	<b>Service to provide</b>	<b>Transit agencies</b>	<b>On-Demand services to partner</b>	<b>Transit to supplement</b>	<b>Incentive</b>
Via to Transit	Los Angeles, CA / King County, WA	First-mile/last-mile solution	Los Angeles County Metropolitan Transportation Authority / King County Metro / Sound Transit	Via, on-demand ride service	Subways / Light Rail / Bus	Partial fare subsidy
Ride2 Eastgate and West Seattle	King County, WA	First-mile/last-mile solution	King County Metro	Chariot and Hopelink	Bus and water taxi	Partial fare subsidy
King County Metro Scoop Carpool Partnership	King County, WA	Transit replacement	King County Metro	Scoop	NA	Partial fare subsidy
Pierce Transit Limited Access Connections	Pierce County, WA	First-mile/last-mile solution; Guaranteed ride home	Sound Transit; Pierce Transit	Lyft	Bus and Light Rail	Full subsidy
BART Carpool to Transit	Bay Area, CA	First-mile/last-mile solution	BART	Scoop	Light Rail	Guaranteed Parking
Pinellas Partnership for Paratransit	Pinellas County, FL	On-demand paratransit	Pinellas Suncoast Transit Authority	Lyft and other contractors	Paratransit	NA
Palo Alto and Bay Area Fair Value Commuting	Palo Alto, CA	Transit replacement	City of Palo Alto	Scoop	NA	Partial fare subsidy

Sources: Gustave, Shaheen and Martin, 2018; Grellier, 2020; Gifford, Chazanow and Hallenbeck, 2021; Shen, Wang and Gifford, 2021; Miller et al., 2021; Martin et al., 2020; King County Metro, 2020

Even though shared mobility has shown competitive advantages, only a small number of transit agencies have implemented TIMOD pilots, and many others are still figuring out ideal ways to implement such pilots. The potential cost-savings of supplementing traditional transit with shared mobility options have not been thoroughly demonstrated for the following two reasons:

- Theoretically, the concept of cost is often vague. While some studies have explored the potential for shared mobility to help public transit agencies achieve cost savings, they have usually compared the average cost of fixed-route services to the cost of shared mobility options (Lazarus et al., 2017; Zhou, 2019). This approach may misinform decision-making because the marginal cost of running fixed-route transit in low-demand areas or for the first-mile/last-mile of travel can be substantially higher than the system-wide average cost.
- Practically, only a few programs have evaluated the cost-effectiveness of TIMOD versus alternatives. Of those that have, the evaluation has been very limited, as they have typically compared the pilot service with non-performance-equivalent alternatives—for example, with past transit lines serving the areas or with different mobility pilots in other areas (Gifford et al., 2021; Grellier, 2020; Ong, 2019). As such comparisons have not controlled for performance, the results may not reflect the actual cost-saving by the pilots.

### 1.3. Research Questions

In light of these research gaps, we initiated this study in collaboration with King County Metro (KCM), the primary transit operator in the Seattle region. The study used KCM's recent TIMOD pilot, Via to Transit, which connects people located within specified service areas to one

of five Link light rail stations. On the basis of this unique policy experiment, which has generated rich data, the study aimed to introduce a rigorous approach that would compare TIMOD with expanding fixed-route services based on their marginal costs. It addressed the following questions:

- What are the conceptual differences between the marginal cost and the average cost of providing mobility service? What are the major components of the marginal costs?
- How do marginal costs differ among expanding traditional transit service (e.g., increasing bus frequencies on existing routes, adding fleet size, or increasing route density), providing park and ride facilities, and providing on-demand services?
- How can public transit agencies empirically estimate and compare the marginal costs of different options using rigorous data-based approaches?

This report proceeds with a literature review of the impacts of app-based shared mobility on urban transportation. It also reviews research works that analyzed the integration of app-based shared mobility with public transit. Then the report presents a theoretical framework based on the economic concept of marginal cost that we believe provides more pertinent information for decision-making for TIMOD projects. Next, the report introduces a transportation simulation procedure that allows transit agencies to empirically compare the marginal costs between traditional service expansion and a TIMOD project. Applying this approach to the case of Via to Transit, the report demonstrates how the results can effectively help evaluate TIMOD projects and inform future decision-making. The report closes with discussions and conclusions.

## CHAPTER 2. LITERATURE REVIEW

### 2.1. Impacts of App-Based Shared Mobility on Urban Mobility

The question remains whether app-based ride-hailing, the most popular form of shared mobility, can benefit urban transportation as a whole (Tirachini, 2020). Studies have found that app-based ride-hailing usage is negatively associated with automobile usage, and therefore, app-based ride-hailing has the potential to reduce car ownership and parking needs (Clewlow and Mishra, 2017; Henao and Marshall, 2018, 2019; Wang et al., 2021). Some studies have suggested that app-based ride-hailing has equity benefits, as it grants socioeconomically disadvantaged neighborhoods adequate automobile access (Brown, 2019). However, many others have assumed that the benefits of app-based ride-hailing are rarely empirically supported. Both individual-level travel survey analysis and aggregated-level regression analysis have found that app-based ride-hailing directly competes with public transit and is likely to take transit riders away (Clewlow and Mishra, 2017; Diao et al., 2021; Graehler et al., 2018; Henao and Marshall, 2018; Rayle et al., 2016). Furthermore, studies have found that app-based ride-hailing has exacerbated road congestion (Diao et al., 2021; Erhardt et al., 2019; Tarduno, 2021)

One of the important reasons that app-based ride-hailing has failed to deliver its theoretical benefits is its low passenger occupancy rate. In addition, the benefits of such limited mobility sharing are often offset by the empty miles that drivers spend cruising for customers. It is therefore important to investigate alternative types of mobility services that can better achieve “deep sharing” (Shen et al., 2021). Shen et al. (2021) studied app-based carpooling in a TIMOD pilot and encouraged transit agencies to explore partnering with app-based carpooling, which has a much higher level of passenger occupancy rate than app-based ride-hailing. Another study,

Tirachini et al. (2020), called for integrating shared modes in bigger vehicles (e.g., vans) rather than app-based ride-hailing.

Given these findings, transit agencies should be selective regarding what mobility services to incorporate, as some forms of shared mobility services may not provide the assumed mobility-sharing benefits. Transit agencies also need to be strategic about where to launch the pilots, what specific services to offer, what incentives to provide, and how to rigorously evaluate the outcomes.

## 2.2. Research on Integrating App-Based Shared Mobility into Transit

Although empirical cases are limited, as many TIMOD pilots are still under development, several studies have developed innovative approaches to come up with useful recommendations for designing such pilots.

Some studies have analyzed or simulated scenarios in which supply-side, fixed-route transit is supplemented with on-demand shared mobility services. Zhou (2019) introduced a procedure to identify low-demand service routes using smart card data, and suggested that replacing them with shared mobility modes could generate cost-savings if the on-demand modes had an occupancy rate of greater than two. Studies such as Shen et al. (2018) and Gurumurthy et al. (2020) have used agent-based modeling to simulate performance gains under scenarios of on-demand services (in their case, automated vehicles) to replace buses as first-mile/last-mile connections to urban rails.

Other studies have conducted travel surveys to understand the potential of shared mobility from the demand side. Yan et al. (2019) analyzed commuters' responses to a proposed TIMOD system and predicted the resulting mode choices. They found that the proposed TIMOD service could improve the transit system's performance primarily by reducing riders' waiting

time. Zgheib et al. (2020) collected stated preference data for the three stages of transit trips (i.e., access, in-transit, and egress) and modeled the mode choice of using app-based ride-hailing to access transit. They estimated that the introduction of app-based ride-hailing as a feeder mode to transit could attract an additional 2 percent commuters to transit, and the effect would be greater if subsidies were provided. Focusing on low-income neighborhoods, Yan et al. (2021) and Wang et al. (2022) conducted in-depth analyses of low-income travelers' preferences for a proposed TIMOD service. They found strong preferences for the TIMOD service over traditional fixed-route transit, in particular among respondents who were underserved by the existing transit and who had adopted app-based ride-hailing. They also identified that low-income travelers' technological self-efficacy could be a major barrier to adopting TIMOD.

While contributing to the early understanding of TIMOD projects, these previous studies were exploratory. The supply-side simulations assumed that a hypothetical new mobility service was introduced, while the demand-side survey analysis mostly relied on respondents' stated preferences. Therefore, the insights obtained by these studies have limited practical values in guiding current transportation decision-making.

### 2.3. Defining the Costs of Different Service Provision Options

Cost-efficiency is a key argument for initiating TIMOD projects. However, the concept of cost in related literature has often been vague for two reasons:

- The total economic costs of mobility service consist of both the service provider's cost and the users' cost. However, not all these components have been explicitly accounted for in previous studies. For example, for research that examined hypothetical services (Gurumurthy et al., 2020; Shen et al., 2018; Wang et al., 2022;

Yan et al., 2019), the service provider's cost was often not considered. Similarly, users' cost may not have been fully estimated (Yan et al., 2019; Zhou, 2019).

- While it is critically important to differentiate between the average cost and the marginal cost, previous studies have not clearly made the distinction (Lazarus et al., 2017; Zhou, 2019). The system-wide or route-wide average cost of traditional transit has often been implicitly—and inappropriately—compared with the marginal cost associated with the incremental improvement of TIMOD projects.

#### 2.4. Current Evaluations of TIMOD Projects

Another group of studies have consisted of transit agencies' self-evaluation or third-party evaluation of existing TIMOD pilot studies (Gifford et al., 2021; Grellier, 2020; Gustave et al., 2018; Martin et al., 2020b; Miller et al., 2021). Most studies have utilized TIMOD service trip records and user survey data and have examined the usage of TIMOD services, trip characteristics, and the socio-demographics of riders. Some studies have probed the effects of the on-demand services in boosting transit ridership (Gifford et al., 2021), and others have looked at the cost-efficiency of the TIMOD pilots (Martin et al., 2020b; Miller et al., 2021). Ong (2019) conducted one of the most comprehensive efforts, in which the author compared the service provider's cost of operating on-demand mobility services in a TIMOD pilot versus that of running fixed-route transit. The result showed that the pilot had a relatively high operating cost. However, as the author acknowledged, the comparison did not consider the users' costs, and such costs are very likely to differ substantially among different types of services.

In general, the evaluations of existing TIMOD pilots have not been satisfactory for two reasons. First, many reported benefits, such as the quick adoption of on-demand services, shortened travel times, and even boosted transit ridership, have not been surprising, given that

the transit agencies typically offered special incentives. Second, the costs of TIMOD pilots have often been compared with those of non-comparable alternatives, such as fixed-route transit and TIMOD projects in a substantially different setting. This is because transit agencies can only observe implemented TIMOD pilots and their outcomes, without knowing what the costs would be in the counterfactuals, i.e., when TIMOD pilots were not available, and traditional fixed-route transit was deployed to meet the demands.

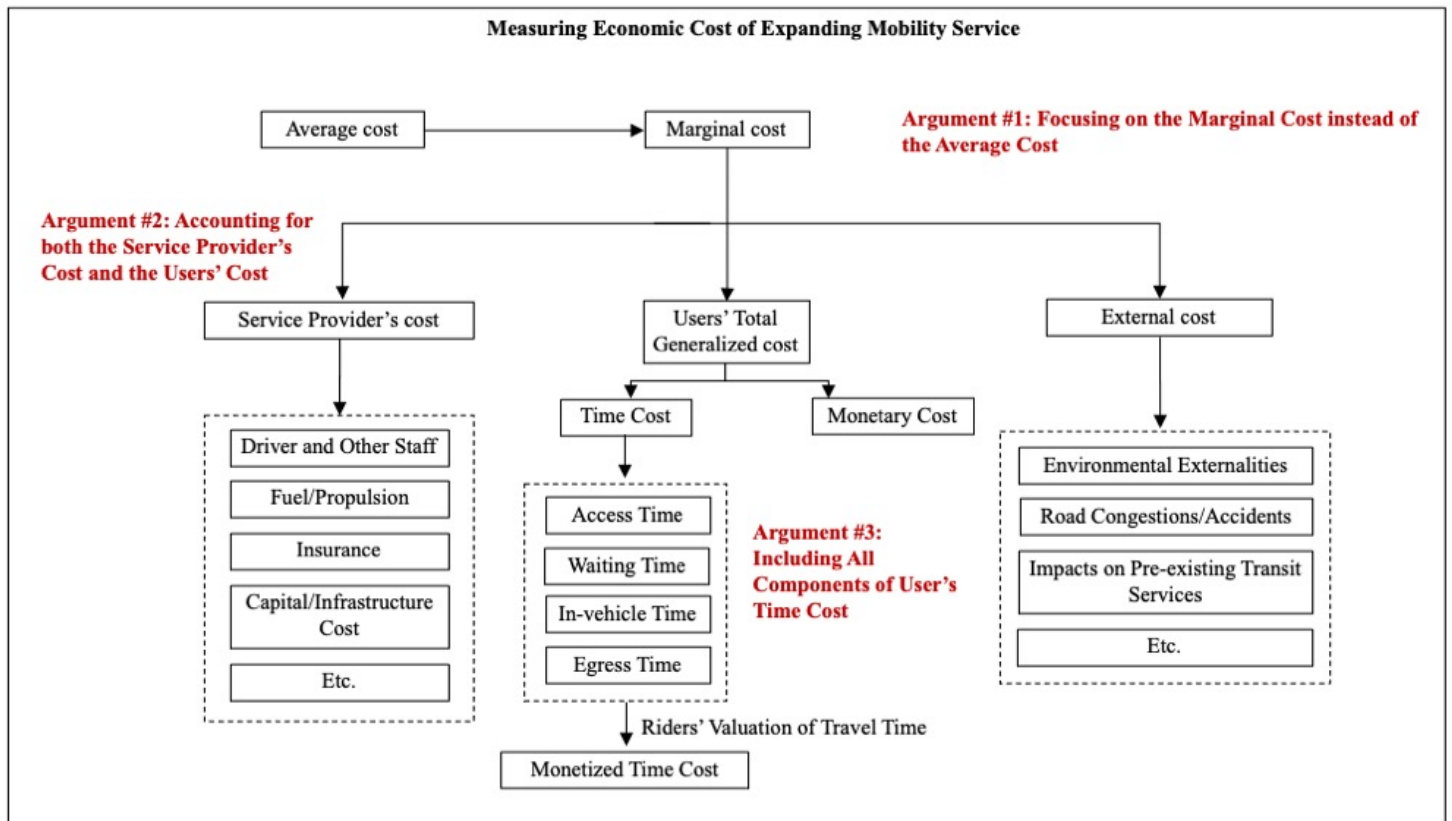
The key question should be, instead, how the benefits of TIMOD projects compare to those of traditional fixed-route transit expansions with the same funding. To address this question, this study developed a rigorous and effective approach. First we developed a theoretical framework built upon fundamental economic principles, and then we applied this framework to make comparisons among different mobility service delivery options.

To sum up, while transit agencies are exploring the integration of app-based on-demand mobility options, a rigorous and effective framework is lacking to allow transit agencies to evaluate the cost-effectiveness of different options. The following chapters attempt to fill in this gap. We first propose a theoretical framework that helps clarify the costs of alternatives and appropriately compare the marginal costs of different service options. Guided by this theoretical framework, we then use transportation modeling to demonstrate that such costs can be empirically estimated.



### CHAPTER 3. CONCEPTUALIZING THE COST OF THE SERVICE PROVISION

Figure 3.1 illustrates our proposed theoretical framework for quantifying the total economic costs of expanding mobility service to a new or underserved area with either traditional fixed-route service options (e.g., increasing bus frequencies/service hours on existing routes, increasing vehicle size, and/or adding new routes), TIMOD projects (e.g., incorporating ride-hailing, ride-splitting, micro-transit, carpooling, and/or bike-sharing), or any other types of service provision options. The diagram illustrates the three aspects of vagueness in the current conceptualization of cost, each addressed by an argument from the economic perspective.



**Figure 3.1** Theoretical framework for conceptualizing the economic costs of different service provision options

### 3.1. Thinking from the Perspective of Marginal Cost instead of Average Cost

When public transit agencies consider expanding current services or adding new mobility options, they think at the margin. In comparison to the average cost, which is the total system-wide cost divided by the total number of services provided, the concept of marginal cost provides more pertinent information for decision making. The marginal cost refers to the extra cost associated with a one-unit increase in an economic activity, which in our case means one additional unit of mobility service.

The marginal principle guides an economy entity to make optimal decisions. In the context of TIMOD projects, switching from average cost to marginal cost as the basis for decision-making is of particular importance because the projects are typically deployed in areas where extending fixed-route transit would be costly. In such areas, the marginal cost of operating additional fixed-route transit is likely to be much higher than the system-wide average cost. For example, both Miller et al. (2021) and Ong (2019) reported that the cost per ride for fixed-route transit in low-demand areas can be several times higher than the system average, as shown in figure 3.2. Switching our perspective from comparing average costs to marginal costs could help transit agencies identify areas—especially low-demand areas—where shared mobility modes have real competitive advantages.

In real-world decision-making, it is not practical for transit agencies to estimate the marginal cost for a one-unit increase in service. This is largely because the mobility service, as a typical example of public goods, is naturally indivisible. That is, the transit agency is not likely to supply mobility service as one single bus ride or for a single on-demand trip. Therefore, in practice the decision-making units are often more aggregated, such as adding a new bus route,

increasing bus schedules, or launching TIMOD service in a new area. In other words, marginal cost is approximated.

FMLM/Flexible/Low-Capacity Services	Cost Subsidy (\$)
Bike-share	\$8.00*
Lowest 20% of Metro Bus	\$9.50*
Lowest performing bus (607)	\$21.00*
Access Services (complementary ADA paratransit service)	\$39.00

\*Does not include capital costs

COST OF TRANSIT SERVICE	COST PER VEHICLE HOUR	RIDES PER HOUR	COST PER RIDE
Peak Only (Eastgate Routes)	\$ 165.59	29.6	\$ 5.60
<b>Local All Day (Eastgate Routes)</b>	<b>\$ 161.34</b>	<b>17.5</b>	<b>\$ 9.20</b>
Local Frequent (Eastgate Routes)	\$ 161.34	22.9	\$ 7.05
Regional All Day (Eastgate Routes)	\$ 165.59	30.4	\$ 5.45
All Metro Operated (System Average)	\$ 163.89	31.7	\$ 5.16
Lower 25% (System Average)	\$ 161.37	16.5	\$ 9.78
Hopelink-operated (System Average)	\$ 122.90	11.3	\$ 10.92
Access Paratransit (System Average)	n/a	n/a	\$ 60.63

Source: King County Metro 2018 System Evaluation and other Metro internal data.

**Figure 3.2** Comparison of cost per ride for LA Metro bus system (top) and KCM bus system (bottom)

Sources: Miller et al. 2021 and Ong 2019

### 3.2. Accounting for Both the Service Provider’s Cost and the Users’ Cost

To thoroughly estimate the marginal cost of different service options, one needs to decompose the marginal cost to the service provider’s cost, the users’ cost, and external costs. For public transportation, the service provider’s cost is the cost for transit agencies to operate the service, which typically includes the cost of labor (i.e., drivers, service managers, and planning

staff), fuel/propulsion, capital costs, insurance, etc. The users' cost is made up of the monetary cost and the time cost of travel, which is commonly known as generalized travel cost. External costs, also known as externalities, include environmental externalities associated with vehicle use, road congestion, and road accidents. External costs also include the impacts on pre-existing transit services of providing a new service. For example, the TIMOD service offered may take some riders away from existing bus lines. While conceptually important, available literature has suggested that the magnitude of external costs is relatively minor in comparison to the other two components (Parry et al., 2007). Therefore, for practical consideration, most transit agencies focus on the service provider's cost and the users' cost when making comparisons among different service options, bearing in mind that external costs may vary substantially from one context to another.

In the case of comparing TIMOD pilots with traditional fixed-route transit, transit agencies typically can estimate the service provider's cost based on the amount billed to them. Similarly, the TIMOD service users' cost can be obtained by observing their travel times and payments. However, as discussed in the literature review, it is challenging to measure both the service provider's cost and the users' cost for unobserved counterfactuals, such as where TIMOD services were not offered and transit agencies instead chose to expand traditional fixed-route transit. Consequently, transit agencies may overlook the reduction in users' generalized travel cost when comparing TIMOD with other options.

### 3.3. Including All the Components of a User's Time Cost

A user's travel time consists of not only the in-vehicle travel time but also the following components:

- Access time from one's origin to the transit stop or on-demand service's pick-up location
- Waiting time for the transit or the on-demand vehicle to arrive
- Egress time from the transit stop or on-demand service's drop-off location to the destination.

Accurately estimating a users' travel time cost requires all the above components to be included. Furthermore, each component can be converted to monetary value based on the user's valuation of travel time.

Figure 3.1 and the three arguments, collectively, clarify the conceptualization of the total economic cost of mobility service provision. The framework includes the capital costs and operation costs for the transit agencies as providers of public goods (i.e., the mobility service), and the time and monetary costs for users to undertake trips to fulfill their travel needs. The framework, however, does not explicitly include some of the external costs of transit agencies, users, and society associated with the service provision. For transit agencies, the framework does not consider the following:

- The external impacts of providing one service on other services that agencies offer; for example, offering TIMOD service may take riders away from existing bus lines;
- The positive externalities of public transit, commonly known as the 'Mohring Effect', i.e., the increasing return to scale of transit service.

For users, the framework does not consider the following:

- Long-term behavioral and attitudinal changes of users and their corresponding economic and societal costs; for example, a mode switch from walking and biking to TIMOD may discourage active transportation that has important environmental and

health benefits, or a mode shift from driving to TIMOD may help lower car ownership and reduce driving for other trips.

For societal costs, the framework does not consider the following:

- Externalities associated with vehicle use, including local environmental pollution, global warming, road congestion, oil dependency, road accidents, etc.;
- Long-term maintenance costs for roads and other infrastructure.

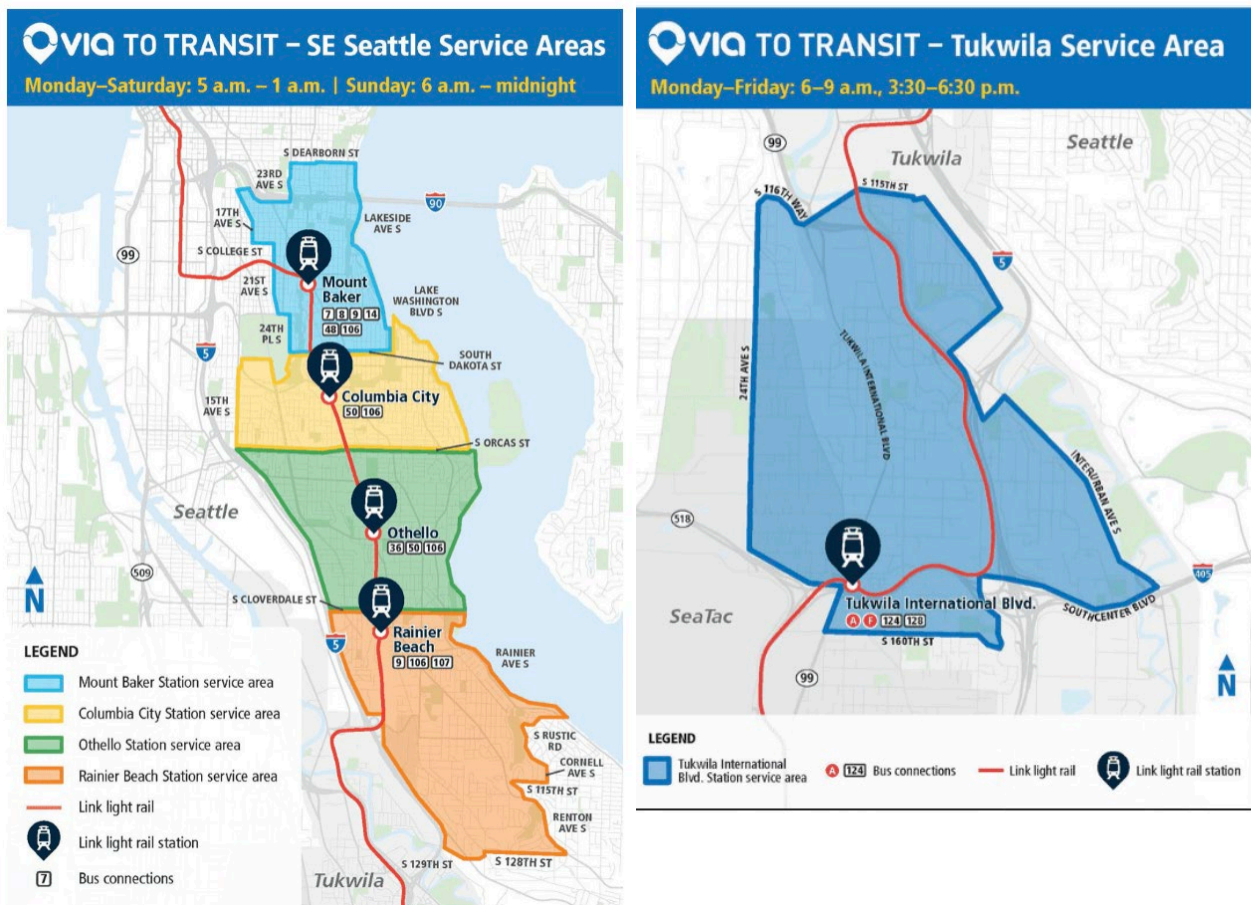
The following sections describe the use of Via to Transit, a TIMOD pilot in the Seattle region, to demonstrate how such a conceptual framework can be applied to the policy evaluation of real-world TIMOD projects.

## CHAPTER 4. SIMULATION FORMATION

The conceptual framework can be applied to analyzing any mode of travel. In the empirical evaluations of Via to Transit we compared the cost of the TIMOD pilots with those of two plausible counterfactual service provision options: expanding traditional fixed-route bus transit and providing park and ride facilities near the Link light rail stations. We estimated the service provider's (i.e., transit agency's) cost and users' (i.e., travelers') cost for each option. This chapter introduces the Via to Transit program, as well as the data and simulation methodology. Chapter 5 presents the simulation results and the estimated costs for on-demand versus traditional options.

### 4.1. The Via to Transit Program

Via to Transit is a TIMOD pilot that allows people located within the specified service areas to request rides to/from Link light rail stations. The program employs on-demand, accessible shared mobility services as a first-mile/last-mile connection to Link light rail. During the study period, the pilot served the following Link light rail stations: Mount Baker, Columbia City, Othello, Rainier Beach, and Tukwila International Blvd. Figure 4.1 shows the five Link stations and the corresponding service areas. Before the onset of the COVID-19 pandemic in 2020, the service operated daily from 5:00 AM to 1:00 AM from Monday to Saturday, and from 6:00 AM to 12:00 AM on Sunday except for the Tukwila station. At the Tukwila station, the service operated between 6:00 AM and 9:00 AM and between 3:30 PM and 6:30 PM on weekdays.



**Figure 4.1** Via to Transit service areas and Link light rail stations  
 Source: Gifford et al. (2021)

KCM contracts with Via, an on-demand mobility service provider, to operate the service with Via’s drivers, vehicles, the Via app, and call center. Via to Transit service uses minivans to operate, and figure 4.2 shows the exterior and interior of such a vehicle. Travelers typically book the Via to Transit rides through the Via app<sup>1</sup>. To travelers, Via to Transit costs the same as KCM’s fixed-route services, as shown in figure 4.3. Riders typically paid the fare with an ORCA card (the smartcard for paying transit fare in the region), while other payment options such as

<sup>1</sup> A call center was available for travelers who did not have access to a smartphone or data plan.

credit cards, debit cards, and mobile payment through KCM's Transit GO app were also available. KCM was responsible for the remaining portion of Via's operating cost.



**Figure 4.2** Exterior and interior of the vehicles that provide Via to Transit service  
Source: King County Metro and Toyota (2020)

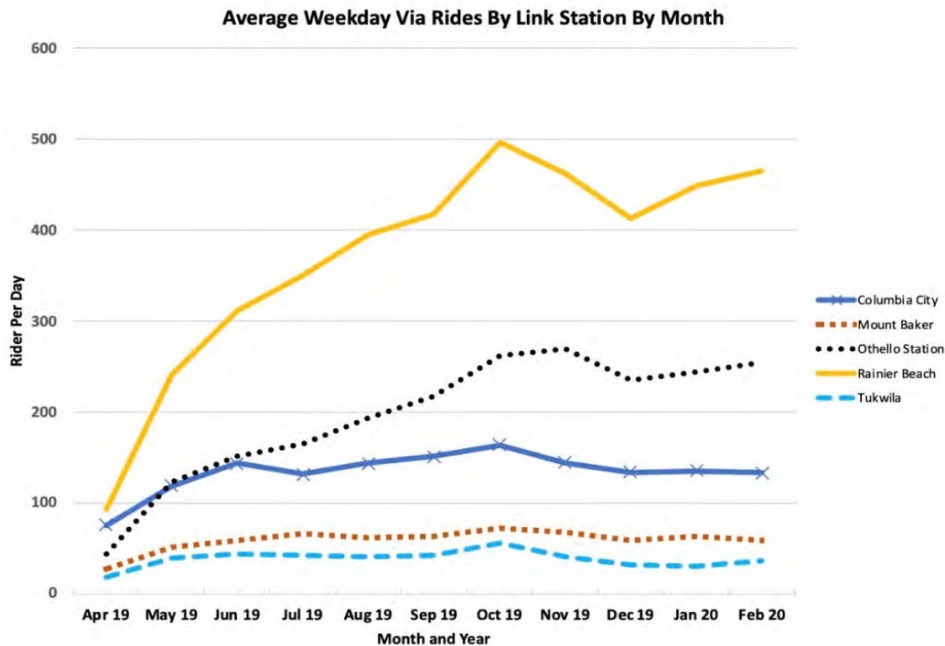
<b>Adults</b> (19 and older)	\$2.75
<b>Youth</b> (6-18 yrs)	\$1.50
<b>ORCA LIFT Cardholders</b> (Income qualified)	\$1.50
<b>RRFP cardholders</b> (registered seniors, Medicare, disabled)	\$1.00

**Figure 4.3** Via to Transit fare (same as KCM standard transit fare)  
Source: King County Metro

Studying riders’ adoption and usage of Via to Transit offers timely, transferrable insights for both KCM and other transit agencies. KCM serves a medium-to-large sized U.S. city, and the Link light rail, operated by Sound Transit, is currently the only light rail line and a “backbone” of the public transit system in the region. Via to Transit thus provides meaningful mobility access within the service areas. Instead of being a short-term, small-scope experiment, Via to Transit originally lasted for a year, from April 16, 2019, to March 23, 2020, and carried about 230,000 trips<sup>2</sup> during that time. As shown in figure 4.4, the ridership of Via to Transit quickly increased from April 2019, peaked around October 2019, and stabilized thereafter. Therefore, its results can shed light on the long-term impacts of such mobility pilots on riders. In addition, the five service areas consisted of neighborhoods with a relatively high percentage of people of color and low-income populations. Studying Via to Transit thus offers invaluable knowledge regarding the social equity implications of such mobility pilots.

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<sup>2</sup> The service was suspended because of the COVID-19 pandemic. In 2021, the service was partially resumed. The data used in this report were from the service operation before the pandemic.



**Figure 4.4** Via to Transit average weekday ridership by station  
Source: Gifford et al. (2021)

In addition, there are a few characteristics of the Via to Transit service that are worth highlighting:

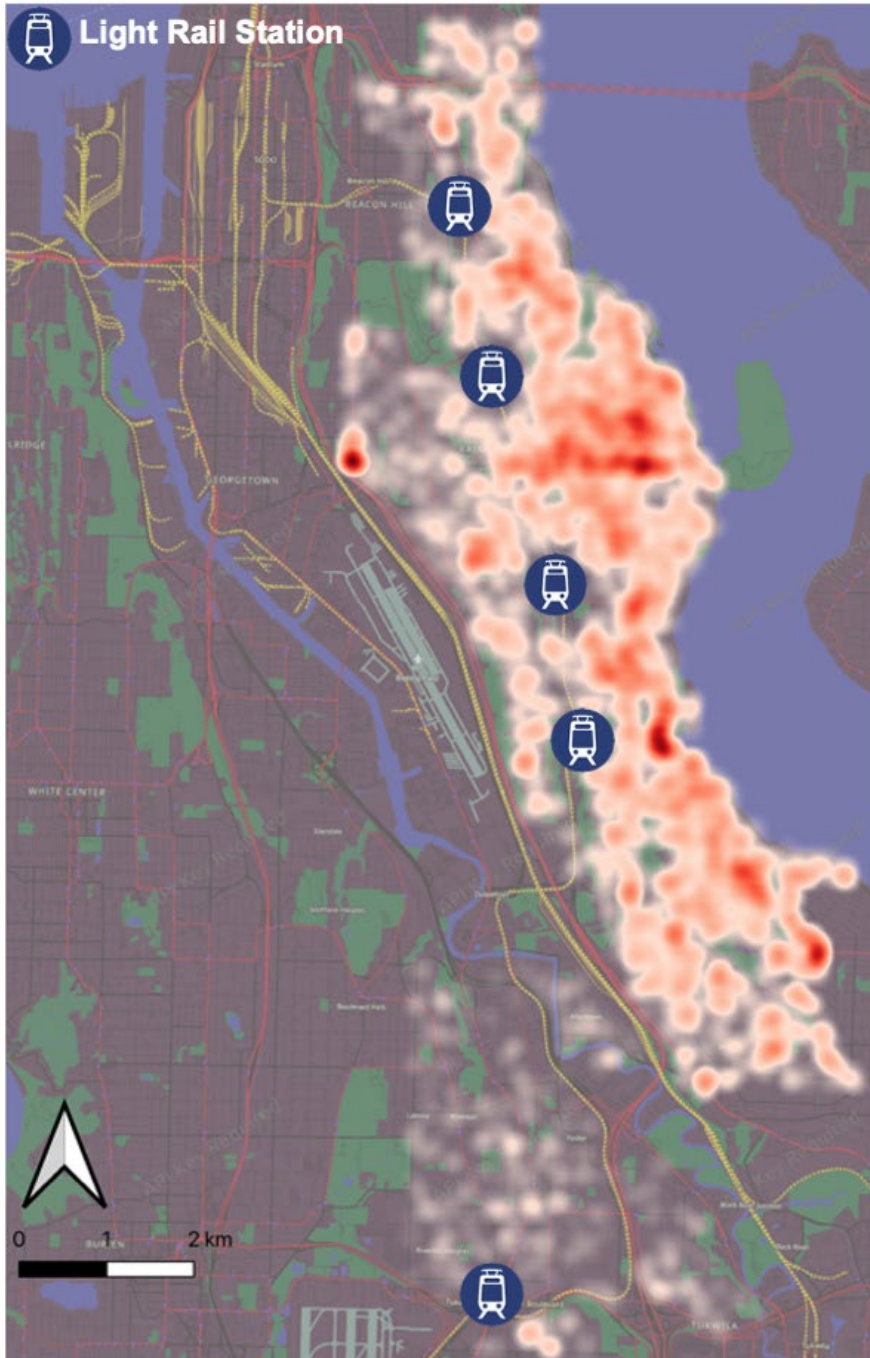
- Via to Transit rides can only be booked on-demand. When customers successfully book a ride, the app informs them about the estimated time of arrival.
- Via to Transit serves any number of travelers, i.e., there is no minimum number of riders for booking the trip.
- Via to Transit rides may be shared by multiple groups of travelers.
- Riders are usually asked to walk a short distance to/from a convenient location for pick-up/drop-off.
- At the pick-up location, Via drivers will wait for travelers for a maximum of two minutes beyond the pick-up time before proceeding to the next traveler.

- Via to Transit is not available for trips to or from locations within a quarter mile of the stations except for travelers with disabilities.

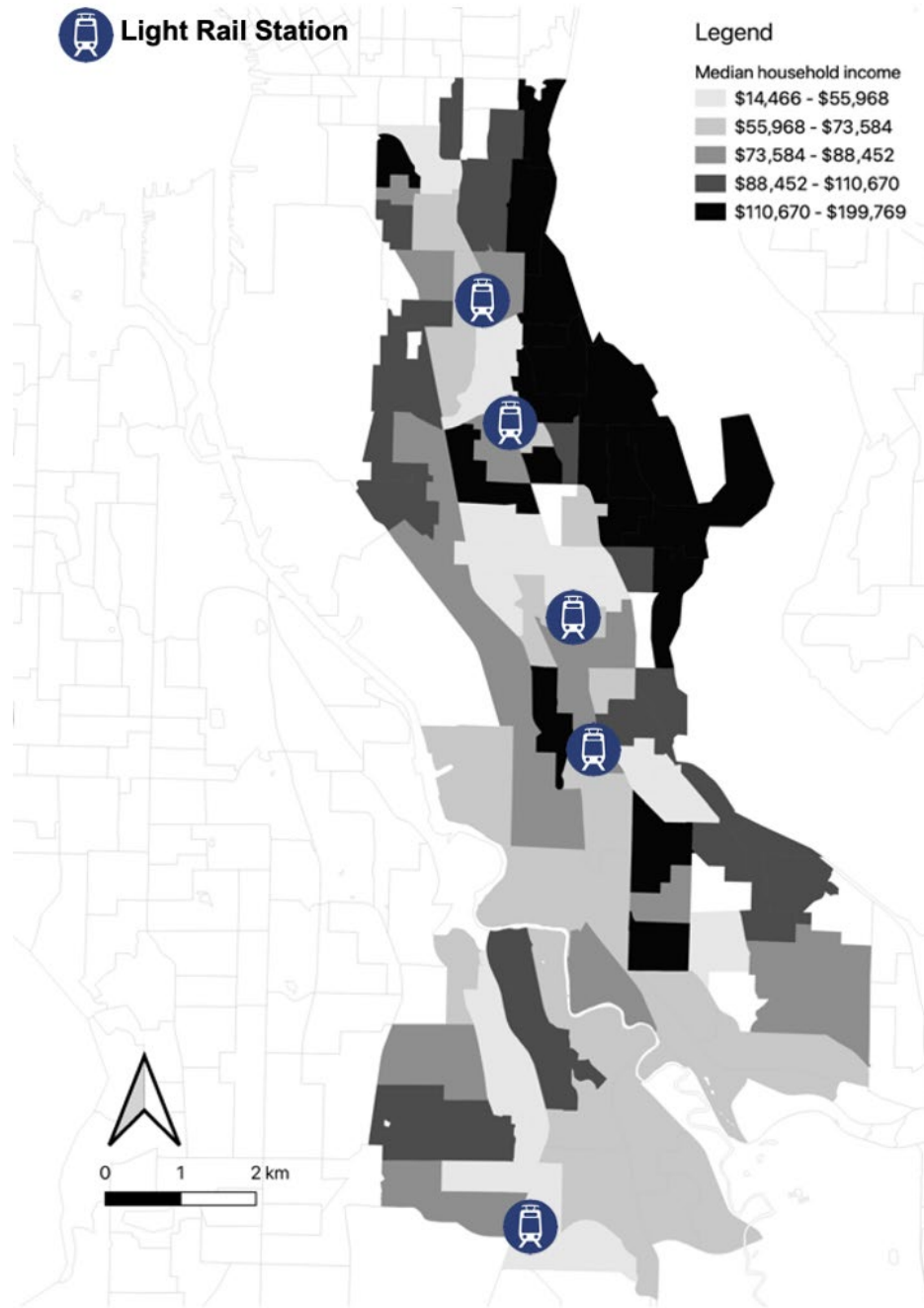
Figure 4.5 shows the distribution of Via to Transit riders' most frequent travel locations, where the darker color indicates locations to which a higher number of riders traveled. This was obtained from Via to Transit trip data. Since trip purpose information was not available for each trip, we were not able to determine whether the most frequent travel location was the rider's home, workplace, favorite restaurants, or other places. The only thing known for sure was that each was one end (either origin or destination) of the Via to Transit trip (the other end was the light rail station), and this was the location to which the riders most traveled. Figure 4.5 shows that there were more riders in the four northern-most service areas, and fewer riders from the Tukwila International Blvd Station service area; however this was likely because the service hours in Tukwila were much more limited than those in the other service areas. Within the most popular four service areas, riders were, in general, spread out, while there existed a few "hotspots" where riders were concentrated.

Figure 4.6 shows the median household income of Census Block Groups in the service areas. Neighborhoods with relatively high median income were those in the north of the area and close to the waterfront on the east, while many neighborhoods in the south were lower income.

Figure 4.7 is the land use map of the Via to Transit service areas, excluding the one of Tukwila International Blvd Station. The area consisted primarily of land zoned as single-family residential. There were commercial/mixed-use and multi-family residential lands along major transportation corridors.



**Figure 4.5** Heatmap of Via to Transit riders' most frequent travel locations (darker color = higher rider counts)  
 Source of the base map: Open Street Map (2015)



**Figure 4.6** Median household income of Census Block Groups in the Via to Transit service areas (with five-quantile classification)  
 Data Source: Bureau of Labor Statistics (2022)



## 4.2. Data and Methodology

For the agency's cost, we worked with KCM staff and obtained their cost measures for each counterfactual scenario. For estimating travelers' generalized cost, this study used Via to Transit trip data, a dataset that recorded every completed Via to Transit trip (N = 229,133). The data included each Via to Transit trip's request, pick-up, and drop-off times (in minutes); origin and destination geo-coordinates (rounded to 3 decimals); trip distance; and number of seats requested.

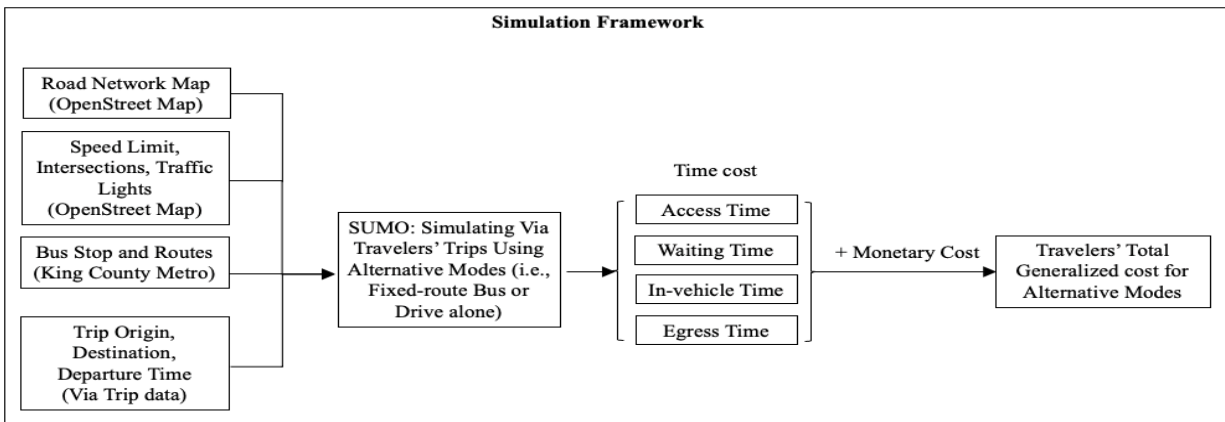
Table 4.1 shows how we calculated the duration of each travel segment (waiting time, access time, in-vehicle time, and egress time) from the original Via request, pick-up, and drop-off timestamps. The difference between pick-up and drop-off times was the in-vehicle travel time, while the difference between request and pick-up time was the sum of waiting or access times. On the basis of the information that KCM provided, on average Via to Transit riders walked for about 5 minutes to designated pick-up locations. Therefore, we decomposed the difference between the request time and the pick-up time ( $\Delta$ ) by using the following rule: if  $\Delta < 5$  mins, then waiting time = 0 and access time =  $\Delta$  mins (Example 1); otherwise, waiting time = ( $\Delta - 5$ ) mins and access time = 5 mins (examples 2 and 3). The egress time in this case was assumed to be 0 mins because Via to Transit dropped riders off at the exact place they requested.

We applied a transportation simulation approach to model the scenarios in which Via to Transit did not exist, and all current Via to Transit riders took alternative modes (in this study, fixed-route transit and driving alone to/from park and ride facilities were the two modes considered) instead. We used Eclipse SUMO, a free and open-source software for the simulation. SUMO is highly customizable and can directly model real-world road networks and individual-traveler-level traffic flows (Lopez et al., 2018). It also allows for modeling multi-modal travel.

**Table 4.1** Calculating the travel time of each segment based on original Via trip data

	Via trip data timestamps			Duration time calculated			
	Request	Pick-up	Drop-off	Waiting time	Access time	In-vehicle travel time	Egress time
Example 1	9:09 AM	9:12 AM	9:20 AM	0 mins	3 mins	8 mins	0 mins
Example 2	1:14 PM	1:20 PM	1:30 PM	1 mins	5 mins	10 mins	0 mins
Example 3	3:15 PM	3:35 PM	3:40 PM	15 mins	5 mins	5 mins	0 mins

Figure 4.8 illustrates our simulation framework. We obtained the road network map and related information on the numbers of lanes, speed limit, permitted vehicle types, sidewalks, pedestrian crossings, and traffic lights from OpenStreetMap, and the bus stop and route information from KCM. In the simulation, travelers departed at the same time when they requested Via to Transit, but instead of taking Via, they took fixed-route bus or drove alone. The outputs of the simulation were the access, waiting, in-vehicle travel, and egress times needed for travelers using either one of the two alternative modes.



**Figure 4.8** Simulation framework for estimating travelers’ total generalized costs using alternative modes

For this simulation, we picked the Rainier Beach station and its service area for the following reasons. First, of the five stations, Rainier Beach had the highest number of Via

Transit rides throughout the pilot period. This indicates that Via to Transit had real comparable advantages for riders in the area. Second, Rainier Beach station was one of the stations to which Via to Transit service resumed after its suspension in response to the COVID-19 pandemic. Therefore, choosing it as the study area had greater practical value than stations where Via to Transit did not resume. We discuss how our simulated results might have changed if a different service area had been selected in the Discussion section. We chose Monday, September 9, 2019, as the date for simulation because its daily trip count was closest to the average daily trip count during Via to Transit's operation<sup>3</sup>.

We simulated four fixed-route bus transit scenarios and one drive alone scenario. In the four transit scenarios, KCM would invest in increasing the frequency of the two existing bus routes, Route 106 and Route 107, by offering more frequent bus service<sup>4</sup>. Routes 106 and 107 were the only two bus routes that connected the service area to the Rainier Beach light rail station, as shown in figure 4.9. The details of the scenarios were as follows:

- Scenario 1: Buses ran at their current service frequency. Route 106 ran about every 15 minutes between 7:00 AM and 7:00 PM, and about every 30 minutes in early-morning and late-night hours. Route 107 ran about every 30 minutes throughout the day.
- Scenario 2: Buses had a 10/15 service frequency. Bus frequency was increased to every 10 minutes during peak hours and every 15 minutes during off-peak hours. For

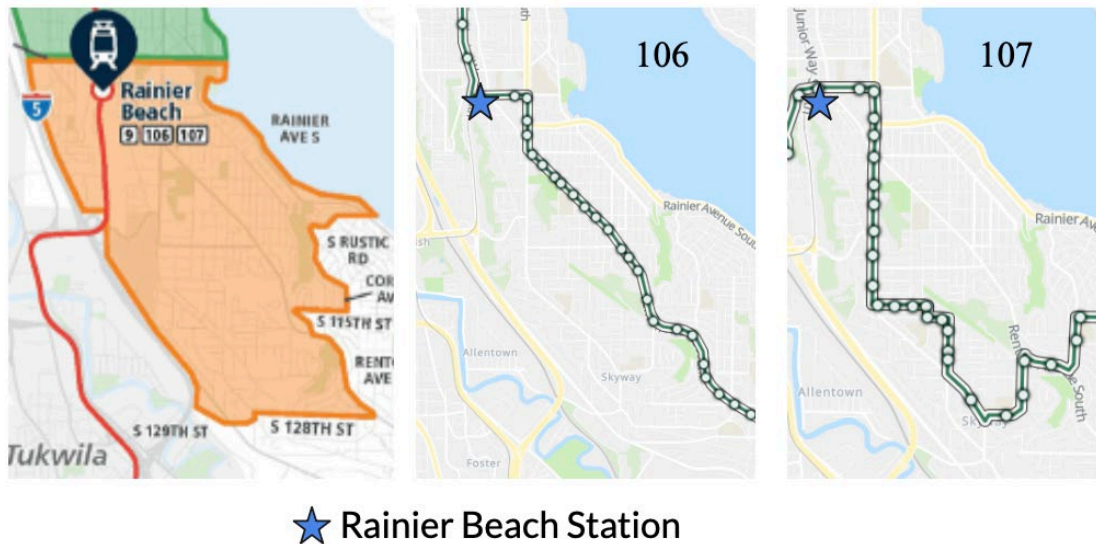
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<sup>3</sup> Strictly speaking, it was a representative date for Via's operations from September 2019 to February 2020. Before September 2019, Via to Transit ridership was still quickly growing. After September 2019, ridership stabilized.

<sup>4</sup> It is conceivable that KCM could expand its existing transit services by adding new stops or routes. However, we believe that increasing service frequency is the easiest improvement that an agency can make, and a similar approach can be taken to simulate other traditional options for service improvement. Therefore, we focused on increasing bus frequency in this study.

this and the following scenarios, we defined peak hours as 7:00 to 9:00 AM and 4:00 to 6:00 PM<sup>5</sup>.

- Scenario 3: Buses had a 5/10 service frequency.
- Scenario 4: Buses had a 5/5 service frequency.
- Scenario 5: All Via to Transit users drove alone. Instead of providing transit services, free parking facilities were provided near the station. Park and ride services are currently provided at other transit stations.



**Figure 4.9** Via to Transit Rainier Beach service area (left), bus Route 106 (middle), bus Route 107 (right)

The simulation was built on several additional assumptions:

- The travel speed for buses and private vehicles during peak hours was 80 percent of their free-flow travel speed.

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<sup>5</sup> This was defined by observing peak hours in Via to Transit trip data.

- Scenarios 1-4: Travelers' trips consisted of an access phase (e.g., for first-mile trips, including walking to bus stops and waiting), an in-bus travel phase, and an egress phase (e.g., for first-mile trips, walking to Link light rail stations from the bus stop). This scenario assumed that everyone could walk, and their walking speed was 3 miles per hour. Travelers were assumed to depart at the time they requested the Via to Transit trip.
- Scenario 5: Every traveler had access to a car<sup>6</sup>; there was a transfer access time (i.e., time spent walking between a park and ride facility and the Link light rail station platform) of 4 minutes.

We validated the SUMO modeling outcomes in Scenario 1 (transit service running at the current frequency) by comparing the resulting travel times with those estimated from Google Transit (Gifford et al., 2021). The two results aligned well with each other, suggesting that the simulation model was appropriately set up.

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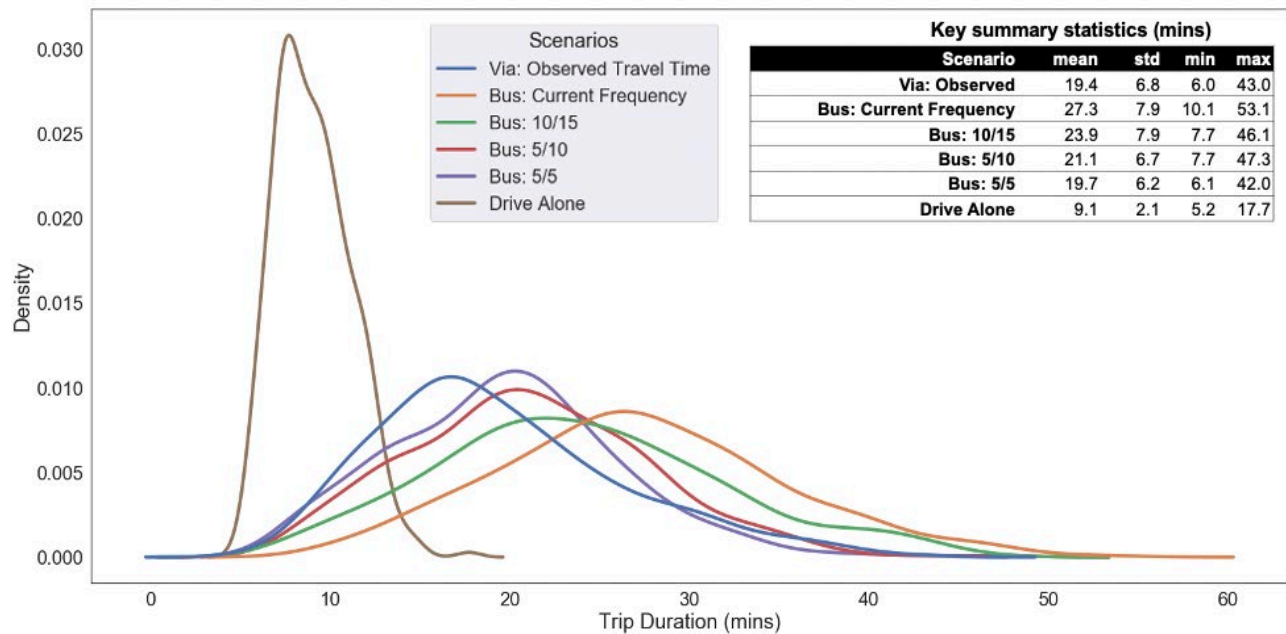
<sup>6</sup> This scenario was hypothetical for simulation purposes. In reality, about 30 percent of Via to Transit riders in the Rainier Beach service area reported that they did not have access to a car.

## CHAPTER 5. RESULTS

### 5.1. Travel Times in Observed and Simulated Scenarios

Figure 5.1 shows the probability distribution of travelers' total travel time for a trip in each scenario. In this figure, the vertical axis shows the probability density for this continuous travel time variable. Via trip travel time was based on observed trip data, while the travel times for the other scenarios were generated by the SUMO simulation.

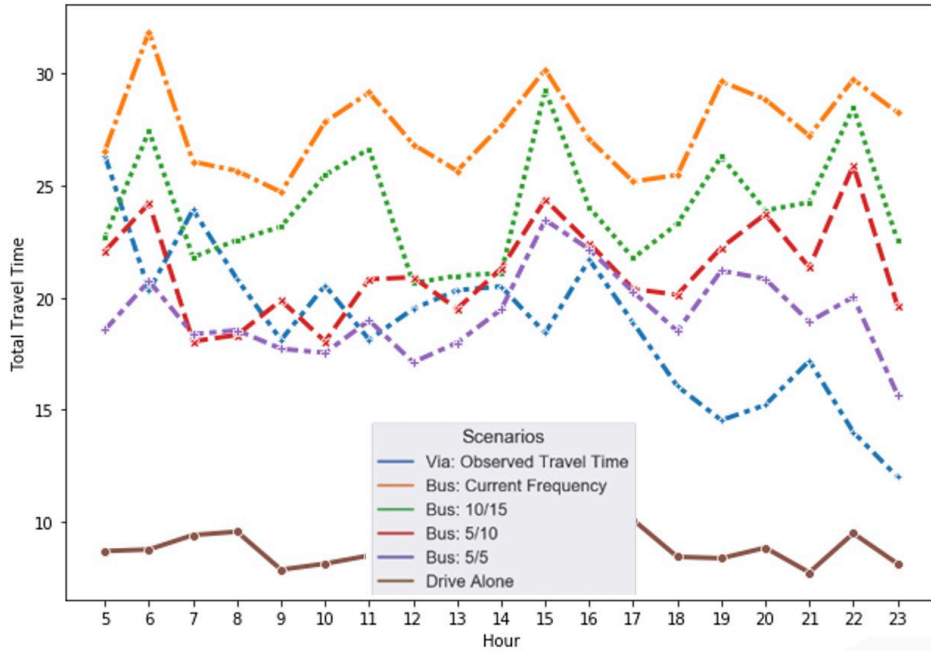
On average, Via to Transit's travel time was 19.4 minutes. If trips were diverted to the two bus routes with their existing service frequency, then the average travel time increased to 27.3 minutes, and the longest trip increased to 53.1 minutes from 43.0 minutes. The average travel time decreased as the bus service became more frequent. If the frequency reached a high level with a 5-min headway, then the bus trip became approximately performance-equivalent to that of Via (19.4 mins versus 19.7 mins). This finding confirms the travel time savings of Via to Transit due to its on-demand, flexible nature in comparison to the fixed-route bus. Driving alone, on the other hand, had a much shorter average travel time than any other option. This is not surprising because driving alone does not require waiting and detouring as Via does.



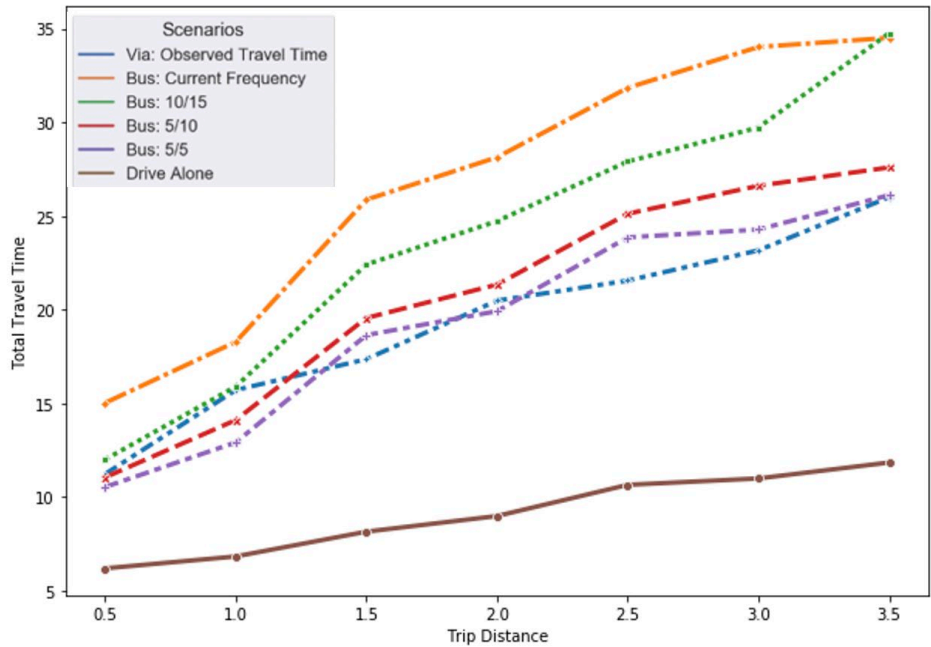
**Figure 5.1** Travelers' total travel time (mins) and distribution in each scenario

Figure 5.2 and Figure 5.3 show the distribution of travelers' total travel time by trip start hour and by trip distance, respectively. The two figures offer more details on the performance of each option than does figure 5.1. Figure 5.2 shows that Via to Transit underperformed in relation to fixed-route bus service with a 5-min headway during daytime hours (7:00 to 10:00 AM and 12:00 to 2:00 PM), but it substantially outperformed during evening hours (after 5:00 PM). This can be explained by the fluctuations of travel demand throughout the day. During peak hours, Via to Transit riders needed to wait longer for their rides and had a higher chance of sharing rides with others, both factors resulting in longer travel times. However, after 5:00 PM, Via to Transit trips had shorter waiting times and a lower chance of detouring. Figure 5.3 shows the comparative advantages of each mode at different trip distances. Via to Transit outperformed transit for relatively long-distance trips. However, for trips with a distance shorter than 1.5 miles,

Via to Transit no longer demonstrated an advantage over buses when the bus frequency was increased to 5/10 or 5/5.



**Figure 5.2** Travelers' total travel time by trip start hour



**Figure 5.3** Travelers' total travel time by trip distance

## 5.2. Estimating Riders' Total Generalized Costs

Based on the SUMO simulation outcomes discussed above, the study converted travel times into monetary values through travelers' valuation of travel time. Travelers' average hourly wage was assumed to be \$35.74 per hour, which is the average wage for workers in the Seattle Metropolitan Statistical Area (Bureau of Labor Statistics, 2020). Travelers' valuations of travel time, in terms of percentages of their hourly wage for each segment of travel, are listed in table 5.1. These parameters were determined on the basis of the following: 1) DOT's guidance on valuation of travel time (White, 2016); 2) current literature describing measured or synthesized values of travel time for traditional and new shared mobility modes (Schwieterman, 2019; Victoria Transport Policy Institute, 2020); 3) the unique characteristics of Via to Transit service as described in Chapter 4.

Some of these parameters were determined with additional considerations as follows:

- For in-vehicle travel time, the percentage for transit was set higher (50 percent of travelers' hourly wage) than that for Via (40 percent), given the level of comfort, such as the availability of seats. The percentage for driving was the highest (60 percent) because drivers cannot freely use their time as passengers. These numbers were determined following the recommendations of White (2016).
- For waiting time, the percentage for transit was set higher (75 percent) than that for Via (50 percent). This is because Via allows travelers to have much better control over where and how to use their waiting time than the bus. These numbers were determined following the recommendations of Schwieterman (2019).
- The monetary cost of driving was estimated at \$0.64 per mile (AAA, 2021). The number included the costs of fuel, insurance, vehicle depreciation and maintenance,

license, and registration. The average trip distance of Via to Transit on the selected date was 2 miles; therefore, the per-trip monetary cost of driving was \$1.28. For Via to Transit and bus transit, travelers' monetary cost was \$2.75, assuming they all paid the standard transit fare.

**Table 5.1** Assumptions about travelers' valuation of travel time and monetary cost

	<b>Via to Transit</b>	<b>Transit (bus)</b>	<b>Drive</b>
<b>In-vehicle travel time</b>	40%	50%	60%
<b>Waiting time</b>	50%	75%	NA
<b>Walking time</b>	100%	100%	100%
<b>Monetary cost</b>	\$2.75	\$2.75	\$ 0.64 per mile

Column C in Table 5.2 shows the estimates for the travelers' total generalized cost. Not surprisingly, driving alone had the lowest generalized cost on the travelers' side. This reflects the reality that when a traveler has access to a personal vehicle and can drive, driving is typically the mode that minimizes one's total generalized cost, primarily because of travel time advantages. Via to Transit's total generalized cost, although higher than that of driving, was lower than those of the four transit scenarios.

**Table 5.2** Estimated travelers’ total generalized cost, agency’s cost, and the total economic cost

A	B	Cost for the Selected Day (N of Vehicle Trips = 371, N of Person Trips = 392) <sup>7</sup>			Cost for Six Months
		C	D	E	F
	Scenarios	Travelers' Total Generalized Cost	Agency's Economic Cost	Total Economic Cost	Total Economic Cost
Observed	Via: Observed Travel Time	\$3,850	\$2,506	\$5,278	\$955,298
Alternative 1: Driving	Park and Ride: Last 50 Years	\$2,571	\$2,654	\$5,225	\$945,708
	Park and Ride: Last 30 Years	\$2,571	\$4,027	\$6,598	\$1,194,149
Alternative 2: Fixed- route Transit	Bus: Current Frequency	\$6,110	\$1,697	\$6,729	\$1,217,949
	Bus: 10/15	\$5,336	\$2,729	\$6,987	\$1,264,647
	Bus: 5/10	\$4,765	\$4,746	\$8,433	\$1,526,373
	Bus: 5/5	\$4,447	\$8,526	\$11,895	\$2,152,995

### 5.3. Estimating Total Economic Costs

This section describes our procedure for estimating the public transit agency’s cost of providing each service option, using the information provided by KCM. These included 1)

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<sup>7</sup> Notice that the average occupancy rate was low for this case, which was function of many factors, such as the spatial temporal distribution of demand, the ways that Via deployed and operated the service, etc.

information that KCM reported to the Federal Transit Administration following the federal standard of transit cost reporting; 2) cost figures from recent transit service expansion cases in the Seattle region.

For Via to Transit, we used the per-vehicle-hour cost provided by KCM. That cost included the wages of drivers and supporting staff, fuel, insurance, and other regular costs such as vehicle maintenance, but not capital costs such as the vehicles and the fare collection device. The intent was to remain consistent with the standard by which transit agencies are required to report the cost of fixed-route transit<sup>8</sup>. We multiplied the per-vehicle-hour cost and the total vehicle hours of Via for the selected day, September 9, 2019, to obtain a daily operating cost of \$2,506<sup>9</sup>.

For fixed-route bus service, our KCM collaborators used REMIX, a public transit planning software, to estimate operating costs. The detailed procedure is described in table 5.3. For each scenario, REMIX took the schedules of routes 106 and 107 as inputs and computed daily operating costs for the schedules (Column C). Such costs measured the route-related total costs of serving riders within and beyond the Rainier Beach area. To obtain the marginal costs for serving the Via to Transit riders, we multiplied the total costs (Column C) by the percentage share of rides attributed to Via riders (Column E divided by Column D). The final estimations are in Column F. Column G is the sum of the costs of the two routes in Column F for each scenario. Again, the costs did not include capital costs such as the bus vehicles and the fare collection device.

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<sup>8</sup> When reporting to the National Transit Database, transit agencies include operating costs that are directly identifiable to each mode/type of service.

<sup>9</sup> The per-vehicle-hour cost is confidential, per a data sharing agreement with Via, and therefore in the study we report only the daily operating cost in table 5.2.

**Table 5.3** Estimating KCM’s cost for operating bus routes 106 and 107 with different frequencies

Scenarios	Route	Adjusted Route-Wise Daily Cost	Number of Daily Rides	Number of Rides from Current Via Riders	Cost for Meeting Via Demand	Scenario Total
A	B	C	D	E	F	G
<i>Source:</i>		<i>KCM, Estimated Using REMIX</i>	<i>KCM 2019 Route Performance Report</i>	<i>SUMO Simulation</i>	<i>= Column C / COLUMN D * COLUMN E</i>	
Current Frequency	106	\$22,317	5800	234	\$898	\$1,697
Current Frequency	107	\$15,703	2700	137	\$799	
10/15	106	\$30,275	5800	228	\$1,191	\$2,729
10/15	107	\$28,891	2700	144	\$1,538	
5/10	106	\$49,305	5800	204	\$1,734	\$4,746
5/10	107	\$47,229	2700	172	\$3,013	
5/5	106	\$81,656	5800	182	\$2,559	\$8,526
5/5	107	\$78,196	2700	206	\$5,967	

For driving alone, we assumed that transit agencies provided free park and ride spaces. If one parking space served two rides per day, then serving 371 rides would require at least 186 parking slots. We determined that 225 parking spaces would be provided at the light rail station to make sure that 1) travelers would not need to spend an excessive amount of time cruising for parking, and 2) the parking spaces would be sufficient to meet growing demand in the near future. KCM uses \$167,000 as the price per parking stall for permanent, dedicated, structured transit parking, and the cost includes property acquisition, design, and construction. We assumed two alternative scenarios regarding the lifespan of a park and ride facility, one for 50 years and the other for 30 years, each operating 365 days a year. In the case of 50 years, the daily cost of

225 parking stalls would be  $\$167,000/50/365*225 = \$2,059$ . In addition, we assumed one staff member was needed during the service hour for parking enforcement and on-site maintenance, and thus the daily cost for providing parking would be  $\$2,059 + \$35*17 = \$2,654$ . In the alternative 30-year-lifespan scenario, the daily cost would be  $\$4,027$ .

The estimated agency's cost is shown in Column D in table 5.2. Although Via's cost to the agency was higher than that of running a fixed-route bus at current frequency, it was lower than that of every other scenario. In particular, increasing bus frequency to 5/5 resulted in a much higher agency cost ( $\$8,265$ ). Column E in table 5.2 presents the total economic cost for each service option. For driving alone, the total economic cost was simply the sum of travelers' total generalized cost and the agency's cost. For the Via to Transit and fixed-route bus scenarios, each traveler was assumed to pay  $\$2.75$  as transit fare, which would be revenue for the public transit agency that offset part of the agency's cost<sup>10</sup>. Therefore, for these five scenarios, the total economic cost was the sum of travelers' total generalized cost and the agency's cost minus the fare-box revenue, which was  $\$2.75 * 392$  person trips. Column F shows the cumulative cost for six months, based on the assumption that the daily cost was representative of the Via to Transit's operation from September 2019 to February 2020.

Given the above analysis, under reasonable assumptions, Via to Transit had a lower total economic cost than all four scenarios of bus transit. But its cost was slightly higher than the cost of providing park and ride facilities for driving alone, if the parking structure would last 50 years. In the next section we discuss in detail what this result means.

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<sup>10</sup> In reality, the service is provided by two transit agencies, i.e., KCM and Sound Transit. The cost and revenue are shared between them.

We performed some additional sensitivity tests, including an analysis focusing on low-income travelers who were minimum wage earners. The results are shown in Appendix A. Via to Transit remained more cost effective than all four scenarios of bus transit, and its cost was also lower than the those of both driving alone scenarios. This analysis demonstrated greater potential of TIMOD pilots like Via to Transit to serve lower income travelers.

Another additional sensitivity test was for scenarios in which the park and ride facilities were not free to travelers. For example, KCM could charge travelers \$2.75 to use its facilities, the same amount that travelers paid to use Via to Transit or take buses. In such a scenario, the travelers' total generalized cost in Column C would increase by  $\$2.75 * 392 \text{ persons} = \$1,078$ . However, the total economic costs in Column E would remain the same because the fare was collected by KCM and could offset part of the agency's cost.

## CHAPTER 6. DISCUSSIONS

The previous sections discussed how to appropriately compare the cost-effectiveness of TIMOD projects with expansion of traditional fixed-route service. This new approach is built upon fundamental economic principles. Instead of arbitrarily choosing among non-comparable service provision options and making comparisons based on incomplete or inaccurate costs, it accounts for all the components of service provision and quantifies these cost components based on transportation simulation. Such an approach leads to rich policy implications, discussed below.

### 6.1. Incorporating All Components of Costs Prevents Misleading Findings

The results in table 5.2 highlight the importance of incorporating all components of costs. Many previous efforts that have compared TIMOD pilots and expansion of traditional fixed-route service have included only the agency's cost (Miller et al., 2021; Ong, 2019) but not the travelers' costs because the time costs in counterfactual scenarios could not be easily estimated.

By including both travelers' and agency costs, the results in this study clearly show that previous studies have generated potentially misleading findings. Considering only an agency's costs would be equivalent to comparing exclusively the numbers within Column D in table 5.2. More specifically, the comparison would be between the agency's costs for the scenarios Bus: Current Frequency (\$1,697) and Via: Observed Travel Time (\$2,506). In that case, the TIMOD project would more costly than operating fixed-route transit.

However, such a comparison overlooks the substantially higher costs for travelers when they take existing low-performance, fixed-route transit. Our theoretical framework clarifies that travelers' total generalized costs should also be included in an appropriate cost comparison. Our simulation outcomes for counterfactual scenarios demonstrate that when travelers' total

generalized costs are incorporated, the TIMOD pilot is more economically cost-effective (\$5,278) than running fixed-route transit at the current frequency (\$6,729). This result shows the advantages of TIMOD service over traditional fixed-route transit in our service area. In addition, transit agencies should follow our approach and appropriately assess the outcomes of future TIMOD projects.

## 6.2. Cost-Effectiveness of On-Demand Mobility Options Should Not Be Taken for Granted

Although table 5.2 indicates that Via to Transit is justifiable given its comparatively lower total economic cost, this does not suggest that providing TIMOD services would make economic sense everywhere. For example, information provided by KCM showed that the average agency's cost per Via ride for all five service areas was almost twice as high as that for Rainier Beach, mostly because of the other areas' lower service demand. In these other areas, Via would be unlikely to have as much cost advantage; it might even be more costly than simply expanding fixed-route buses. Indeed, KCM recently resumed the Via to Transit program after temporarily suspending its operation in response to the COVID-19 pandemic, but the resumed service covers only three of the five original station areas.

In addition, Via to Transit may not have similar travel time advantages over traditional fixed-route transit, as shown in figure 5.1 in other places. Whether TIMOD can offer faster service than traditional transit depends on the spatial and temporal distributions of demand, as well as how agencies deploy and operate the two services.

Therefore, providing on-demand mobility services may not be optimal everywhere. The implementation of TIMOD projects requires careful decision-making, including especially proper identification of areas where on-demand modes have cost advantages over traditional

modes. More importantly, transit agencies should consider using pilots such as Via to Transit to experiment and help delineate ideal service areas.

### 6.3. Total Economic Cost versus Total Societal Cost

It may be surprising that the cost of driving alone with park and ride facilities is lower than the cost of providing fixed-route transit in table 5.2, assuming that the facilities would last for 50 years. One possible explanation is that our analysis did not include externalities, which would likely be largest for driving alone. It is known that in the U.S. drivers do not pay all the societal costs of driving, for example, road congestion, environmental pollution, and inefficient use of the land as parking facilities. Parry et al. (2007) estimated that the externality cost of driving was \$0.26 per mile in 2020 dollars, which included local pollution, global climate change, congestion, accidents, and oil dependency. On our selected simulation day, travelers would have driven 775.7 miles if all had chosen to drive alone, which would have resulted in an externality cost of \$201.68 in addition to the \$5,225 economic cost in table 5.2. Although the externality cost was small for our one-day simulation, it could be substantial if travelers continued to drive every day to access the Link station. The \$0.26 per mile might also increase exponentially as global warming continues to accelerate.

Another factor not explicitly accounted for was that access to a personal car is not universal. Our simulation assumed that all travelers had access to cars and could drive, which is inconsistent with the general idea that TIMOD projects need to be implemented in areas where many residents face great mobility challenges, primarily because of a lack of automobile access. Similarly, accessing a bus station by walking can be difficult for some people (e.g., people with disabilities) and in certain areas (e.g., in places that are unsafe for pedestrians).



## CHAPTER 7. CONCLUSION

This study deepens our understanding of how to appropriately evaluate the costs of TIMOD projects with a theoretical framework. The research built a simulation model as a proof of concept for the theoretical framework and applied it to a real-world TIMOD program. Together, the theoretical framework and the simulation serve as an effective approach for public transit agencies to determine, contextually, whether engagement with shared mobility service providers is indeed cost effective.

There were several limitations in this study. First, although the simulation served as a proof of concept that our theoretical framework has practical value, there certainly remain gaps between what we simulated and how individuals make mode choices in the real world. In each counterfactual scenario, we assumed all current Via to Transit riders used the same mode, while in the real world riders could choose among a variety of options. The Via to Transit data we obtained were not sufficient for us to develop a discrete choice model to predict the mode choices when Via to Transit did not exist. In addition, our simulation framework could not examine riders' demand elasticity to changes in service and incentives, for example, to a different number of incentives. Future research will benefit from developing discrete choice models that better resemble how travelers choose among travel modes, and coupling the choice models with the simulation model presented in this study.

Second, our study advanced the literature by thoroughly examining the components of total economic cost for expanding mobility services, but not all societal costs were included. Although incorporated in our conceptual framework, the capital costs of acquiring service vehicles and devices were not accounted for in our simulation and empirical analysis of scenarios of Via to Transit and bus transit. In addition, neither our conceptual framework or simulation

models included costs such as positive and negative externalities associated with different modes, costs of building and maintaining road infrastructure, and costs associated with long-term behavioral and attitudinal changes of users. In addition, although providing cost-effective transit service is an important goal, transit agencies, as public service providers, often prioritize other goals such as ensuring equitable mobility services. These additional considerations should be better incorporated into future studies. For example, the simulation and empirical analysis in this study focused on travelers who had adopted the Via to Transit services. Future studies should consider incorporating those who have not adopted the Via to Transit services and should help to understand and address their concerns.

Third, our empirical demonstration was restricted to one service area of one TIMOD pilot. Therefore, future research can build upon this work by estimating and comparing the economic costs in different service areas and/or with different on-demand service options, which will improve the understanding of factors that affect the economic outcomes of supplementing fixed-route transit with on-demand shared mobility services.

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### ADDITIONAL RESOURCES

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**Appendix A** Estimated travelers' total generalized cost, agency's cost, and the total economic cost, assuming a minimum wage (\$ 17.2 per hour)

A	B	Cost for the Selected Day (N of Vehicle Trips = 371, N of Person Trips = 392)			Cost for Six Months
		C	D	E	
	Scenarios	Travelers' Total Generalized Cost	Agency's Economic Cost	Total Economic Cost	Total Economic Cost
Observed	Via: Observed Travel Time	\$2,440	\$2,506	\$3,868	\$700,088
Alternative 1: Driving	Park and Ride: Last 50 Years	\$1,812	\$2,654	\$4,466	\$808,329
	Park and Ride: Last 30 Years	\$1,812	\$4,027	\$5,839	\$1,056,770
Alternative 2: Fixed-route Transit	Bus: Current Frequency	\$3,551	\$1,697	\$4,170	\$754,770
	Bus: 10/15	\$3,170	\$2,729	\$4,821	\$872,601
	Bus: 5/10	\$2,890	\$4,746	\$6,558	\$1,186,998
	Bus: 5/5	\$2,734	\$8,526	\$10,182	\$1,842,942