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King County Metro

APPENDIX B

TECHNICAL REPORT

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Preface

Quantitatively predicting the future of urban mobility is a very challenging undertaking in any environment. The task is fraught with uncertainties in many areas as trends are influenced by regional growth, shifting demographics, changing technologies, economic conditions, and industry decisions, as well as local, state, and federal policy. Inevitably, predicting the future of urban mobility involves evaluating how those new technologies will interact with travelers in a future urban environment. Yet, despite its challenges, such exercises are necessary to provide what insights can be gained from evaluating what is known today, and conjecturing what will be tomorrow. It is critical for urban regions to anticipate as best as possible the changes that will be imposed upon them through new technologies and emerging mobility systems, while at the same time providing the understanding for those regions to implement sound planning and policy.

This report advances this kind of ambitious effort for the City of Seattle and King County and offers insight as to how shared mobility systems could interface with travelers, enhancing accessibility while also facilitating travel in ways that are potentially more energy efficient. The report provides context and classification to the existing shared mobility landscape, detailing the relative advantages of different modes to the traveling public. One of the key impacts that shared mobility brings is greater mobility without the need for personal vehicle ownership. While the dynamics of vehicle shedding and suppression have been studied in previous research of system users, it is entirely a different problem to assess how such effects may scale to a population for which such services are not yet accessible or still gaining acceptance. A number of key questions arise. What is the maximum potential impact of these systems within a broad and diverse population on vehicle holdings? How does the presence of shared mobility influence mode choice and vehicle miles traveled now and in the future? What is the expected scale of pick-up and drop-off curbside capacity needed to accommodate a region when it is served by circulating shared vehicles? Under what conditions and scale could Transportation Network Company systems serve to cost effectively substitute for under-utilized public transit? These are some of the questions explored using in-depth analysis and modeling through a mix of methods suited to address each question. In support of this effort, researchers at the University of California, Berkeley's Transportation Sustainability Research Center (TSRC) reviewed and commented on the report along with others, providing supportive input and feedback on assumptions, methods, and interpretation of outputs. The results provide a snapshot of impacts and opportunities that are presented by shared mobility, and yield recommendations of near and long-term lessons that can guide decision-making in the future. As with every exercise in predicting the future, some forecasted outcomes may not be manifested. But the report serves as an ambitious start, translating what is known today in shared mobility research and transit planning methods to planning a future of integrated services that both enhance mobility and simultaneously reduce energy consumption in urban transportation.

Executive Summary

This Technical Report summarizes the potential impacts of shared mobility services for Seattle and the broader King County region and policy considerations related to these impacts. This report came about through a combined interest from the City of Seattle Department of Transportation (SDOT), King County, and King County Metro to establish an understanding of emerging shared mobility options and the impacts on the agencies' respective missions, planning policies, and operations. The challenge of this report was to establish new methodologies with existing data sets to understand new models of mobility and translate the outputs into actionable policy direction. The analysis seeks to answer two basic questions: (1) "What could happen?" and (2) "What are the impacts?". Shared mobility and automated mobility will have major impacts on mode choice, access, transit integration, right-of-way, and other transportation-related issues.

In the chapters that follow, shared mobility is defined from the consumer's perspective, in that the term 'shared mobility service' is a catchall for any transportation mode where users pay for a trip rendered or for the temporary use of a vehicle. Shared mobility includes any scenario where vehicles are either shared continuously among multiple users (e.g. buses and trains), or shared among different individual users for personal use over discrete time intervals (e.g. taxis, car share, bike share). It includes fixed-route public transit, vanpool, taxi, and fixed rate services, as well as new mobility services such as ridesourcing (provided by transportation network companies), car sharing (including two-way, one-way, and fractional ownership), bike sharing, microtransit, and private shuttles. While SDOT and King County Metro considers transit and vanpool ride share products, most of the analyses measure the impact of new mobility services. Each analysis indicates data used and implications for each of these shared mobility service types. In addition, the report identifies policies related to each model that could foster Mobility as a Service in the region's future.[1]

Building new analytical tools

There is a growing body of shared mobility research covering topics such as public-private partnerships, international best practices, open data standards, mode shift, mobility solutions for aging populations, streamlined fares, emerging technologies, and more. A selection of such research is available in the appendix. The technical exercises in this report build off the vast base of academic work to date to create tools for practitioners in today's quickly evolving mobility landscape.

Sam Schwartz Consulting developed eight analytical exercises to begin to understand various aspects of the impacts of shared mobility. Instead of relying on one or two analyses to provide answers, the process was built on several analyses creating a panoramic snapshot of the impacts of shared mobility today and what could occur in the future. The tools in this report were built in collaboration with SDOT and King County Metro with the intent of providing an initial understanding of how shared mobility can impact the city and region and serving as a first step for future analyses. Most importantly, a diagnosis of how these models will impact policy decisions was included to provide an important step in identifying the issues and opportunities of new and emerging modes.

Several analyses were performed for this study to identify the impacts of shared mobility services on the transportation network in Seattle and King County. The purpose is to take the outputs of those analyses and use them to inform decision-making processes that complement stakeholder values that were identified in a series of workshops. These analytical tools explore various aspects of mobility, such as consumer response, transit provision, and spatial requirements of different modes and are a first step in identifying impacts of shared mobility.

1 Mobility as a Service (MaaS): A concept that emerged in Scandinavia, it is a mobility model based on commodifying trips and seamlessly facilitating the sale and purchase of trips (from both public and private companies) through a common user interface that integrates all modes available. This concept was popularized by the MaaS Alliance, http://maas-alliance.eu/

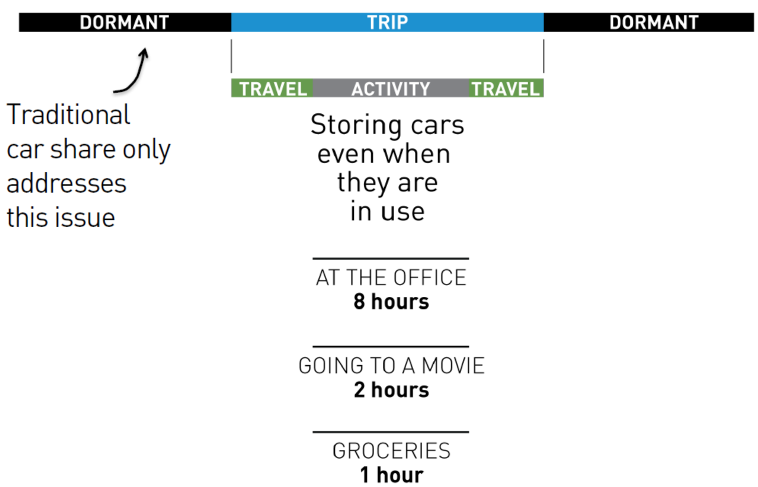
The opportunity to reduce car ownership

A key focus of these analyses is how shared mobility could reduce car ownership and/or single occupant vehicle (SOV) trips in King County. As mobility options continue to evolve, expand, and mature, many people will have the opportunity to give up their car, or decide to not purchase one in the first place. Prior to the widespread arrival of shared mobility, driving single-occupancy vehicles to get around has been one of the primary choices as many transit connections are limited when traveling outside the city center from suburb to suburb or in off-peak periods. This new reality would be economically liberating due to the average cost of car ownership in King County, at approximately $12,500 per year by recent estimates.[2]

Shared mobility options, and the technologies that enable them, increase the possibilities for how people can travel. Results estimate that up to 17-22% of existing vehicles in King County could be eliminated if cost was a consumer's only consideration in deciding whether to switch to shared mobility options. This approach estimates an upper bound of vehicle shedding potential as an attempt to predict the potential for a decrease in personally owned vehicles, but does not consider lifestyle choices, convenience, or geographic prevalence of shared mobility options.

Personal vehicles are often used for a small portion of the day, roughly 4-6%, to travel to work, run errands, or go to an activity. Personal vehicles largely sit dormant at night and between travel. When a vehicle is not being operated, it takes up space in parking lots, garages, and streets. Storage of these vehicles is a burden on the available public right-of-way and built form of our cities, which could be used for more productive uses that serve a larger number of people than the vehicle owner.

Figure 1.1: Traditional use of a vehicle



Shared mobility services, such as Transportation Network Company (TNC) and car sharing, increase the productivity of privately owned vehicles, giving them the ability to serve multiple users through multiple trips throughout the day and even night. In short, shared mobility services increase the latent capacity and efficient use of vehicles that otherwise would be underutilized and absorb valuable space. A tremendous opportunity exists to reallocate precious urban space as the need to store cars is reduced. An initial analysis using trip generation calculations suggested a relatively small amount of space is needed to serve different land uses and entire neighborhoods when people can access destinations

2 Balk, Gene. "Second-biggest expense likely out in your driveway." The Seattle Times (Nov 10 2016). Available at: http://www.seattletimes.com/seattle-news/second-biggest-expense-likely-out-in-your-driveway/

without needing to store their vehicles. While the need for parking will always exist, the analysis suggests that some land uses could easily be served by a few pick-up spaces for shared mobility vehicles or taxis.

Network benefits of shared mobility options

Shared mobility has already begun to play a significant role in the transportation ecosystem in Seattle and the broader King County region. Several services provide coverage in underserved areas, providing redundancy for public transit, and increase options for "first and last mile" connections. These services have to potential to replace single occupancy vehicle (SOV) trips. This analysis leveraged the Puget Sound Regional Council (PSRC) Travel Demand Model to understand these implications on mode choice and vehicle miles traveled in the year 2030. If vehicle mode share was reduced by 25% or 50% by 2030[3] the demand model suggests that there could be a 10% reduction in SOV peak trips in the region and 45% in Downtown Seattle. Using the same inputs, the region could see an increased transit use of three times the current share, from 2.9% to 11.4%.

These benefits would be provided in a paradigm where high quality fixed-route transit is expanded in the future serving hundreds of thousands of riders. At the same time, the analyses identify a starting place where microtransit or transportation network companies (TNCs) could complement the fixed-route transit network at a lower cost than bus service, especially at off-peak times.[4]

Finally, looking further into the future we discovered the potential to completely change the way people get around. A study in Stockholm[5] identified that shared automated vehicles, operated as a ride-matching network, could accommodate all car commute trips with only 10% of the current vehicle fleet.

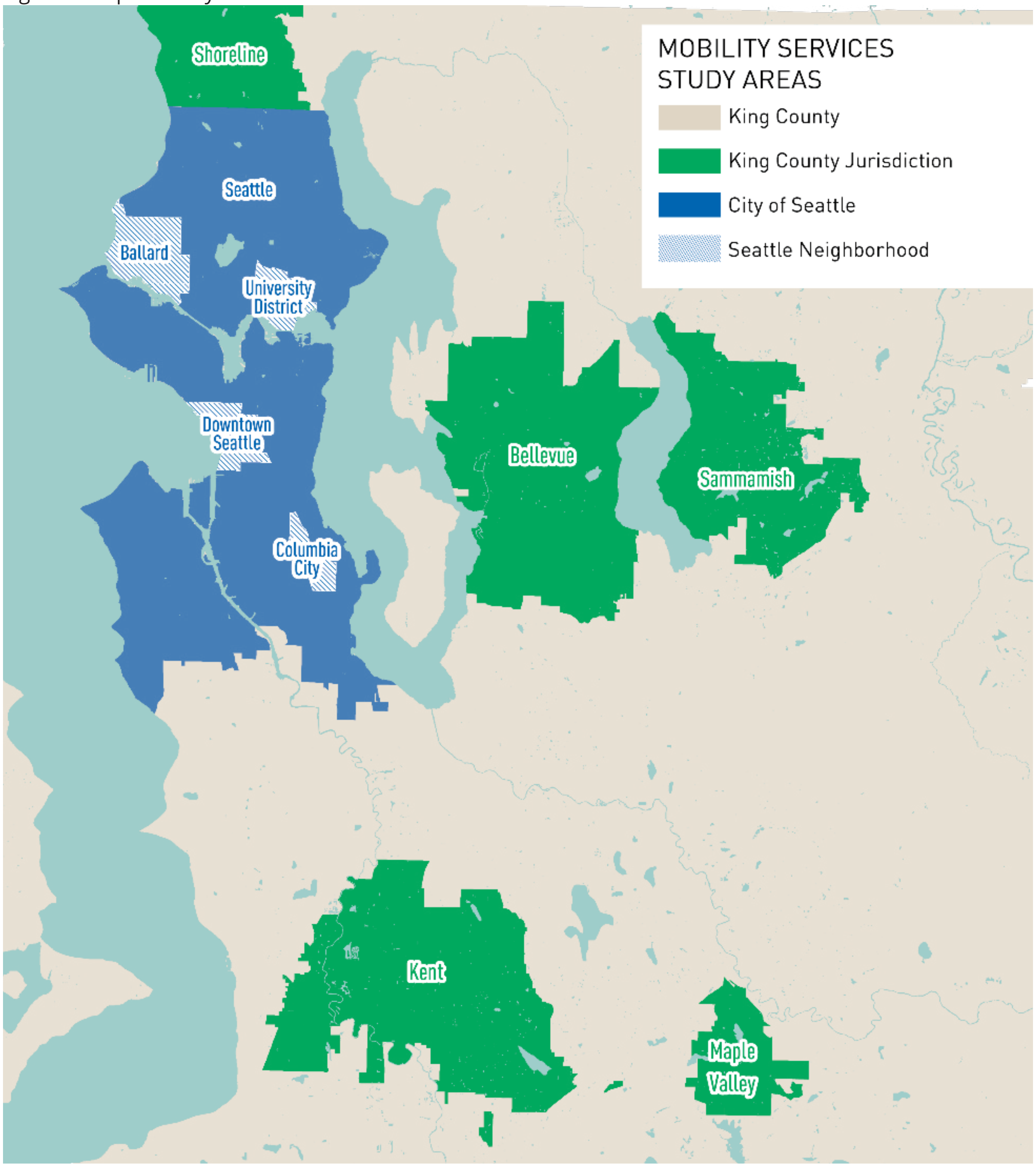
The purpose, methodology, results, and policy implications are included in the following eight chapters and appendix. Each analysis is outlined with limitations and suggestions for future use. In addition, select chapters include results for select study areas representing varying urban and suburban typologies in Seattle and King County (see Figure A).

3 These reductions are not suggested policy goals of either SDOT of King County Metro. These figures were used as inputs into the travel demand model to understand the range of mode shift.

4 This assumes continuation of subsidized transit with the current low cost to user.

5 Rigole, Pierre-Jean. Study of a Shared Automated Vehicles Based Mobility Solution in Stockholm (2014). Kungliga Tekniska Högskolan, Royal Institute of Technology. Available at: http://kth.diva-portal.org/smash/get/diva2:746893/FULLTEXT01.pdf

Figure A: Report study areas



Chapter 1: Social Utility Exercise

1.1 Exercise Logic and Methodology

Social utility describes any service that provides benefit to the majority population in a society. Applied to the mobility landscape, social utility is the ability of various transportation modes to support positive or minimize negative policy outcomes. This planning exercise supports an initial understanding of the potential impacts of shared mobility on factors such as congestion, accessibility, user costs, and space requirements. The exercise is a ranking of the overall social utility of each mode in relation to one another based on informed value judgments. Each mode is ranked on a scale of 1 to 10 based on a set of criteria. Scores of 1 to 4 represent little to no benefit to society, 5 represents a neutral social utility, and 6 to 10 represent a positive effect on social utility.

The criteria used to evaluate the social utility of each mode include:

- Space efficiency when in motion/ congestion
- Accessibility
- Equity
- Vehicle miles traveled (VMT)
- Cost to user
- Parking requirements and land use
- Curb space use
- Potential for car-free lifestyles
- Healthy/active lifestyle related to use of service
- Greenhouse gas (GHG) emissions

The results of this exercise show that each transportation mode has a net social utility based on its impacts on the public realm, the environment, and equity. The social utility exercise was created through analyses of the inherent capabilities of each transportation mode. Criteria such as space efficiency, parking requirements, and curb space help to understand each mode's impact on public space. Considering equity (access to transportation services for people with different economic and social statuses) and accessibility (access to transportation services for people with disabilities) identifies disparities between modes for different users. Many factors are context specific, such as the cost to own, operate, and maintain a single-occupancy vehicle or whether public transit is beneficial to the environment (i.e. if buses have low ridership and are mostly empty). In other cases, the mode may not be currently available in a suburban context, which is noted in the results. To account for issues associated with context specificity, this exercise assumes a relatively dense area in an urban core. Holding transit-oriented land use and urban form constant allows for a comparison among all modes and a base understanding of the function of shared mobility. The rankings may not be unanimously agreed upon by policy makers or members of the public, but is an important starting point for further discussion.

1.2 Results

The model results are based on a scale of 1 to 10 (1 being the lowest, 10 the highest). Social utility by mode is exhibited in two methods below, from the perspective of the social utility indicator (Figure 1.1) and the mode (Figure 1.2). Figures 1.3 through 1.9 provide further definition of the mode and its impact to social utility. The rankings are further exhibited in Table 1.1 on page 12.

Figure 1.1 Mode Scoring by Social Utility Indicator

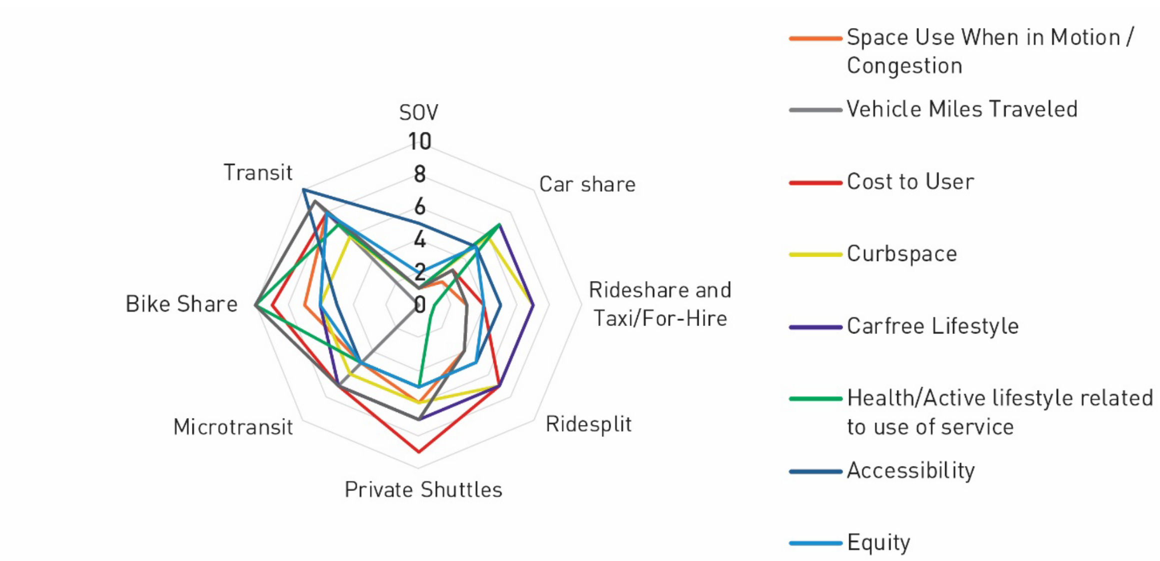


Figure 1.2 Social Utility Indicator Scoring by Mode

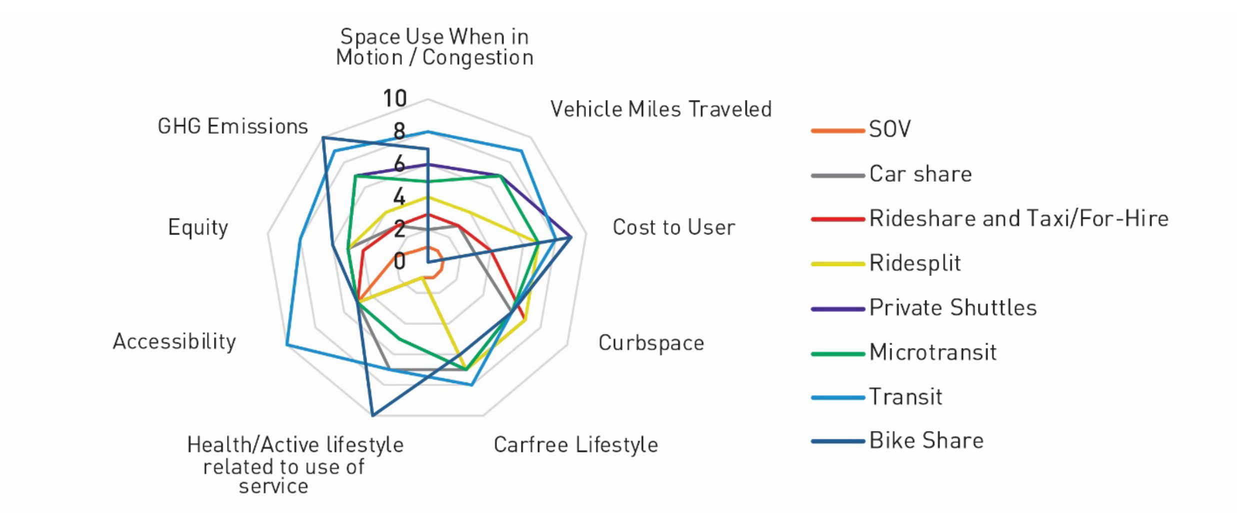


Figure 1.3 Single- Occupancy Vehicle

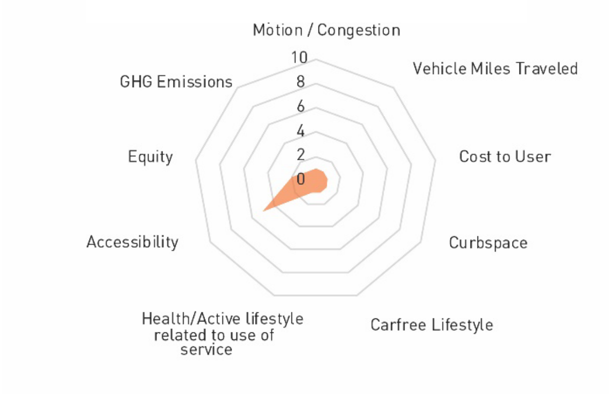
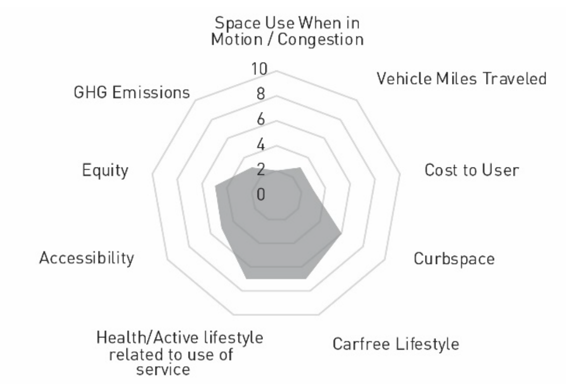


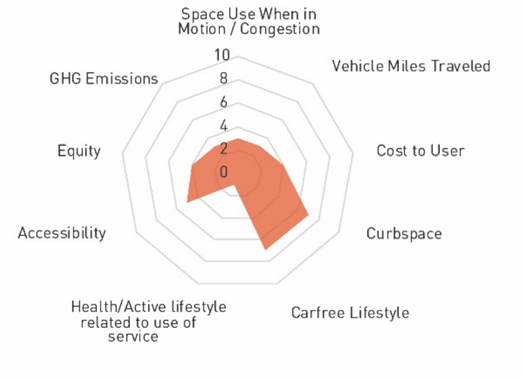
Figure 1.4 Car Share



Single Occupancy Vehicle (SOV) – Single Occupancy Vehicle describes the mode of travel whereby only the driver uses a private vehicle. SOVs are ubiquitous in transportation networks across all geographies and are the primary mode of travel for many commuters. As compared to other modes, SOVs require the most amount of space per passenger transported than any other travel mode and contributes significantly to vehicle miles traveled, and land use storage requirements (parking spaces, curb space, and parking lots). Owning and operating a private vehicle relative to other travel modes is a large expense, unaffordable to some while a true economic burden to others. The sunk costs of auto ownership often result in higher usage, and when combined with other factors contributes to increased traffic congestion (notably during peak hours) and higher volumes of greenhouse gas emissions. Other negative impacts include poor user health outcomes, which have broader implications for society.

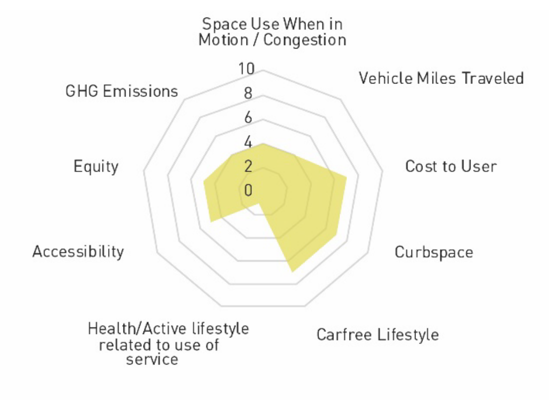
Car share – Car sharing is a membership based rental service offering unlimited access to a network of shared vehicles on a per trip basis. Roundtrip car share and one-way car share are two models present in the region. Roundtrip car share users begin and end their trip at the same location and are charged by the hour, mile, or both. One-way car share users pay by the minute and can begin and end a trip at different locations. Car share has a similar social utility to SOVs, such as space required for parking requirements. As the cost of the vehicle is relegated to each company and spread over many users, it provides a lower cost solution to temporary private vehicle access (cost differs based on service model). The required curb space and capability to provide users with the option to not own a personal vehicle are factors that improve car share's net impact on social utility. One-way car share may more successfully allow for a car-free lifestyle, as user can pair trips with other modes and do not have to pay for the time they are at their destination (i.e. shopping at the grocery store). However, drawbacks to car share include the limited regional distribution of services based on population density and barriers for low-income, un-banked, or disabled residents.

Figure 1.5 Rideshare and Taxi/For-Hire



Rideshare and Taxi/For-Hire– Point-to-point service has been offered for over a century with traditional taxi services. These have been effective for key traffic generators (i.e. hotels and airports), and as a dispatch service. Ridesharing services provide a similar service, but utilize mobile applications as the dispatch and can offer greater information sharing with GPS technology. While the trip purpose is very similar (providing point-to-point trips for customers), TNCs such as Uber, Lyft, and Wingz provide services to customers with the use of non-commercial vehicles. Passengers and drivers are connected exclusively through online means, often with mobile applications. Rideshare and taxi vehicles take up the same roadway space as personally owned SOVs and contribute to the region's VMT (potentially more than SOVs because of frequent 'deadheading' when a driver is traveling to pick up a passenger). In addition, queuing of rideshare and taxi vehicles to pick-up or drop-off customers can be an issue during peak periods and events, but takes up a fraction of the space for these activities compared with parked SOVs. Ridesharing provides benefits to the public as a practical last mile connection to public transit options and allow people in some areas to live car-free. Many areas throughout the U.S. have some form of rideshare or taxi service, though they are not always equitable geographically and financially, or accessible to persons with disabilities.

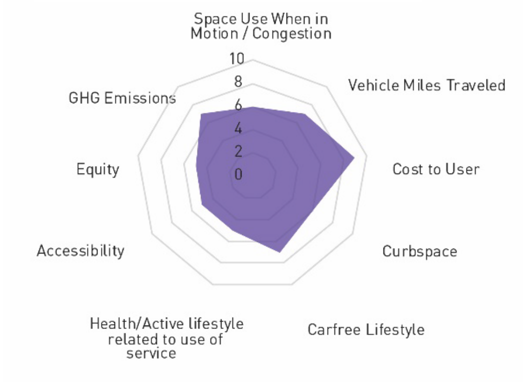
Figure 1.6 Ridesplit



Ridesplit – Ridesplit refer to those TNCs that provide ride matching services as part of or in addition to rideshare options. Examples such as uberPOOL and Lyft Line allow customers to split the cost of the fare among other riders at the expense of potentially longer wait and in-vehicle travel times. Like ridesharing, ridesplit vehicles require less curb space due to brief pick-up and drop-offs (as compared to SOVs parking for extended periods), have the potential to reduce congestion, and can increase capacity of the right-of-way. The service area for uberPOOL includes Seattle and some surrounding areas (Kirkland, Redmond, Bellevue, and Renton) and Lyft Line is available in Seattle (from International District to University District including Belltown, South Lake Union, Capitol Hill, and Fremont). Ridesplit services currently operate in large cities with high population density.[6]

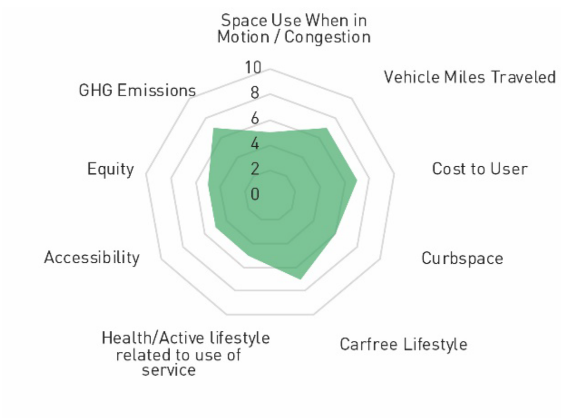
6 As of February 2017, UberPool and Lyft Line operate in around 15 U.S. cities: https://www.uber.com/ride/uberpool/ and https://help.lyft.com/hc/en-us/articles/213815178-Lyft-Line-Pricing

1.7 Private Shuttles



Private Shuttles – This mode of transportation typically transports employees between their place of employment and transportation hub connections. Private shuttles, like the Microsoft Connector[7] and the Amazon Ride[8] (among others), typically have zero user costs. Yet, because these systems are generally closed to the broader public, their social utility is limited, by definition. Benefits of private shuttles to the public include higher capacity thereby reducing congestion and allowing those with access to a private shuttle to consider shedding their personal vehicle if there are alternative modes available for discretionary trips. Private shuttle services can be found in areas with employment centers and central business districts.

Figure 1.8 Microtransit

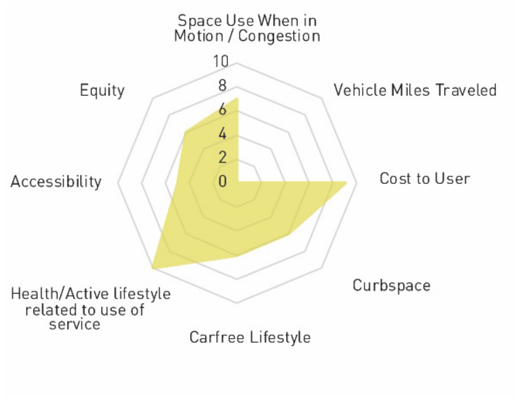


Microtransit – A new privately-owned and operated transit solution known as microtransit provides both commuter and non-commuter shuttle services to the general public. Similar to TNCs, Microtransit companies such Via, Chariot or Bridj rely on mobile applications to connect users to the service. These services can be designed to pick up users in designated geographic zones along deviated fixed routes, or can be dynamically routed based on demand. Microtransit is beneficial for filling in gaps in the public network, lowers congestion if users switch from personal vehicles, and has a lower transportation cost compared with SOVs and the other transportation modes in this analysis with exception to transit and bike share. Microtransit services that complement public transit should not be redundant with existing routes or services. At the time of writing this technical report, none of these services were available in King County.

7 Microsoft Connector information available at: http://wstc.wa.gov/Meetings/AgendasMinutes/agendas/2010/July13/documents/20100713_BP8_MicrosoftConnectorCommuteFactSheet.pdf and https://www.connectorride.com/Account/Login

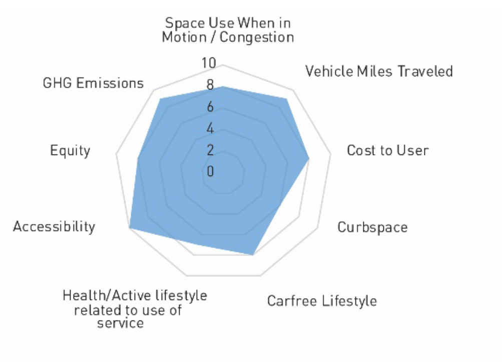
8 Amazon Ride information available at: http://www.geekwire.com/2016/amazon-quietly-debuts-commuter-shuttle-program/ and https://amazon.thebus.mobi/#/

Figure 1.9 Bike Share



Bike Share – Public bike share systems make a network of bicycles available for shared use to individuals on a short-term basis. Although there are various forms of bike share systems, the most common are those with fixed docking stations. Social utility indicators are scored highly, as the bikes themselves produce no emissions, have relatively low cost to users, and enhance active and car-free lifestyles. The drawback of bike share is that as a mode it may not be accessible to all of the public, such as those with disabilities, children, or the elderly. However, some bike share systems are beginning to develop adaptive bicycles to serve these populations.[9] Many major cities have some form of bike share. While Seattle's Pronto Bike Share ceased operation as of March, 2017, other cities are expanding their systems and experiencing high ridership. Bike share takes up much less roadway space compared to SOVs and have the potential to contribute to health benefits from physical activity.

Figure 1.10 Transit



Transit – Public transit encompasses a variety of modes including buses, streetcars, light rail, commuter rail, shuttles, and ferries. In King County, public transit is provided by Metro Transit and Sound Transit. Transit is typically the mode with the highest accessibility, is widely available, and the most affordable option. Public transit is the only mode required to follow Title VI regulations to ensure equitable service coverage. Buses and trains have the highest capacity (people per square foot) relative to other modes and have positive effects on lessening congestion at peak hours. As a publicly-available mode, users can often live car-free lifestyles where transit service is provided.

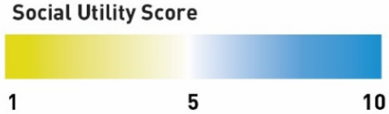
According to this assessment, SOVs provide the lowest social utility, whereas public transit and public bike share programs offer the highest social utility. Table 1.1 reflects the social utility that each mode provides, as represented above. It is important to note that no weighting has been identified for each category and the overall ranking will differ based on context.

9 Adaptive Bicycling Pilot Project. Portland Bureau of Transportation. Available at: https://www.portlandoregon.gov/transportation/article/582518

Table 1.1: Social Utility Indicators by Mode

CRITERIA	TRANSPORTATION MODE							
	SOV	Car share	Rideshare and Taxi/For-Hire	Ridesplit	Private Shuttles	Microtransit	Bike Share	Transit
Space Use When in Motion / Congestion	1	2	3	4	6	5	7	8
Vehicle Miles Traveled	1	3	3	4	7	7	9	9
Cost to User	1	3	4	7	9	7	9	8
Curbspace	1	6	7	7	6	6	6	6
Carfree Lifestyle	1	7	7	7	7	7	6	8
Health/Active Lifestyle Related to Use of Service	1	7	1	1	5	5	10	7
Accessibility	5	5	5	5	5	5	5	10
Equity	2	5	4	5	5	5	6	8
GHG Emissions	1	3	3	4	7	7	10	9
Social Utility Rating	Low	Medium	Low	Medium	Medium	Medium	High	High
Suburban Applicability	Yes	Limited	Yes	No	Limited	No	Limited	Yes

Social Utility Score



Suburban Context Considerations

Population density, employment density, access to a high-frequency transit network, and other factors may limit the suitability of bike share, car share, ridesplit, and microtransit in some suburban contexts. The remaining modes (ridesource, transit, and private shuttles) provide service throughout the region, but at a limited availability compared to the dense urban centers. This is because shared mobility services generally require dense urban conditions to be financially viable enterprises or require subsidies. This may change in the future with the potential introduction of shared automated vehicle fleets where operation costs would be significantly lowered, allowing for expansion in the suburban regions.

For example, bike share and car share often require a large subsidy or have limited availability in areas with low population density where a continuous network is not available. The exception is closed-loop systems that are usually contained on college or corporate campuses. Zipcar has recently launched bike share to complement car share systems on college campuses and could be a model for suburban expansion.[10]

Another consideration for suburban contexts is that rideshare, taxis, and fixed-rate for-hire services may be valued higher in exurban areas because it is the only alternative to driving and the enhancement in mobility has a high value in a mobility-scarce atmosphere. Additionally, rideshare vehicles may not have

10 Zipcar and Zagster launch Zipbike, the first national, sponsored bike-share program for universities (2016). http://www.zipcar.com/press/releases/zipbike

the negative externalities of congestion in exurban areas that, by their geographic location and lack of trip generators, do not have current congestion issues.

The availability of these services does not necessarily change the social utility, but practical considerations must be made when creating partnerships or sponsoring new services to ensure mobility and policy goals are achieved.

1.3 Lessons learned

The intent of this exercise is to show the relative costs and benefits of shared mobility in relation to SOVs and each other. The quantitative analysis is meant to be a planning exercise to help the user identify the potential social value of different modes for a variety of factors.

As the ranking of the factors is highly context specific, conducting this exercise in the framework of a high density urban environment provides points for discussion but also introduces limitations. This exercise should be adapted for more specific contexts and unique issues if possible.

Emphasis or weighting of individual values will impact the relative social utility. For instance, if equity is of high value in an area that does not have congestion issues, then car share and rideshare may score much higher in a similar analysis. This emphasis may be seen as mid-sized metro areas or suburban regions fully embrace shared mobility.

As some shared mobility models are in their early stages, latent demand realized in the future as services become more widely accessible may affect pricing and cost to users. Social utility must be continuously re-evaluated to account for changes in pricing and demand.

This analysis is a first step to help socialize the relative costs and benefits of shared mobility options compared with SOV and other modes. Other uses for this analysis beyond this purpose will require additional research.

1.4 Policy Implications

The findings identify that all shared mobility modes have a higher social utility (or public benefit) in comparison to SOV ownership. Transit and bike share provide the highest social utility in relation to the rest of the private shared mobility modes, but have limitations in market capabilities. This further identifies the value of both (1) investing in transit and bike share and (2) continuing to pursue partnerships with shared mobility providers, especially to support high-occupancy modes.

This exercise can be completed on a smaller scale and incorporate public input when planning shared mobility pilots and making decisions regarding potential partnerships.

Identifying the social utility of transportation modes allows for a first step in considering how a true Mobility as a Service model could affect social utility. Implementing MaaS may mean balancing positive impacts of one mode (e.g. low GHG emissions of bike share) with negative impacts of others (e.g. VMT of car share). This could be achieved through prioritizing service coverage or offering subsidies for modes with higher net social utility. While true MaaS may not be implementable in the next few years, prioritizing modes with high social utility may begin to manifest in the design of shared mobility hubs.

Chapter 2: Economic Model

2.1 Model Logic

The emergence of shared mobility transportation options and an expanding high-quality transit network could result in a reduction in personal vehicle use and ownership in the coming years. The opportunity to reduce vehicle ownership is important in cities for the following reasons:

1) Vehicle ownership creates an incentive to drive more to capture the value of their investment
2) Reduced vehicle ownership encourages more transportation alternatives, transit, car sharing, active transport, etc.
3) Shifting to transit and other shared mobility options will significantly reduce household transportation costs
4) A decrease in vehicles reduces the need for residential and commercial parking, creating the opportunity to use limited space for a more productive purpose

The Economic Model explores the potential for shared mobility services to replace the need for vehicle ownership. From a purely economic perspective, the initial analysis of the potential for TNCs, such as Uber or Lyft, to reduce vehicle ownership identified significant cohorts within King County and Seattle car owners that would experience an economic benefit from giving up their car and using rideshare or ridesplit (at current market prices) for their travel needs.

The economics of mode choice is one of the foundations of consuming mobility as a service. The Economic Model is based on the idea that ridesharing and ridesplitting can provide a comparable alternative to driving a single-occupancy vehicle in regard to time, customer experience, and direct pick-up/drop-off at an individual's origin or destination (although users further from the urban core may experience longer wait times with less prevalence of such services). In other words, when considering vehicle miles traveled (VMT), car ownership costs, and shared mobility costs, there is a point where it becomes economically rational for consumers to switch to rideshare instead of using their personal vehicle. This model is a first step in estimating potential vehicle shedding (getting rid of a vehicle) but does not explicitly capture potential vehicle suppression (the decision to not buy a vehicle in the first place due to the presence of shared modes).

A limitation of focusing solely on economic rationale is that decisions to travel by personal vehicle or rideshare, which often vary by individual or household type, may not be captured. For example, a household that includes multiple adults and small children might consider convenience and comfort before, or in tandem with, financial decisions. Current shared mobility systems may struggle to serve families with children, regardless of how much those households drive, when factors such as multiple pick-up and drop-offs, carpooling, and car seats are included.

With these limitations in mind, this model helps us to understand the potential for a reduction of personal vehicles, which could result in increased right-of-way capacity (from reduced parking demand or pooling), decreased need for parking space, decreased greenhouse gas emissions, lower consumer costs, and a redundancy in transportation options. In other cases, a reduction in personal vehicles and congestion which frees up roadway space, may "tap into" latent demand of single-occupancy vehicles.

The following modes were utilized as options in the Economic Model:

- Rideshare
- Ridesplit
- Transit
- Car share (one-way model)
- Automated vehicle rideshare
- Automated vehicle ridesplit

Transit is the only subsidized mode while the rest are privately operated. The cost per user differs for each mode and is based on current pricing in the region. While shared automated vehicle services are not yet available, they are included in this analysis to begin to understand their potential impact on private vehicle ownership.

2.2 Methodology and Assumptions

As the Economic Model is a purely cost-driven approach, the methodology produces an upper bound of possible vehicles that could be shed. Since personal vehicle ownership is motivated by more than just cost, the definition of market size by purely cost parameters will inherently produce an over estimate of the market size.

The methodology is broken down into five steps:

1. Calculate user costs of all modes- personal vehicle, TNC, transit, car share, and TNC automated vehicles.
2. Determine per mile user cost of personal vehicle versus TNC, transit, and car share as a function of annual miles driven. In other words, when the vehicle miles traveled (VMT) increases, what happens to the cost of operating and maintaining the vehicle?
3. Calculate the total number of vehicles for each geography by vehicle type.
4. Determine the total vehicles miles traveled where it would be cheaper for a person to give up their personal vehicle and use shared mobility and/or transit instead.
5. Develop scenarios that include different combinations of shared mobility modes to model the potential personal vehicle reduction. A timeframe for vehicle reduction was not included in this analysis.

Step 1: Calculate annual costs of each mode

Personal vehicle costs- Car ownership data from AAA includes the cost of license and registration, fuel, maintenance, tires, insurance, depreciation, and finance for small, medium, and large sedans. The average vehicle costs per mile, along with parking costs and fuel efficiency, are inputs for private vehicle ownership costs.

Table 2.1: Personal Vehicle Cost Estimates

Cost Type	Small sedan	Mid-size sedan	Large sedan (SUV or Minivan)
License, registration, taxes ($/year)	502.00	701.00	838.00
Insurance ($/year)	1,169.00	1,208.00	1,212.00
Lease payment / depreciation ($/year)	2,568.00	3,792.00	4,639.00
Financing ($/year)	481.00	698.00	800.00
Fuel cost ($/gallon)	2.12	2.12	2.12
Fuel efficiency (MPG)	23.88	22.64	19.38
Maintenance, repair, tires ($/mile)	0.055	0.066	0.068
Parking ($/year)[11]	3,528	3,528	3,528

Rideshare costs- Rideshare costs were calculated using Uber customer costs in the Seattle area in 2016. Inputs for rideshare include base fare ($3.30/trip), mileage fee ($1.37/mile), and a time fee ($13.20/hour). Surge pricing, an increase in rideshare cost to the user based on time of day or location, was not included in the analysis.

Ridesplit costs- The cost of rideshare is discounted by 25 percent for ridesplit services (i.e. UberPool and Lyft Line). Acknowledging that ridesplit cost could vary based on the TNC, costs were calculated using Uber customer costs in the Seattle area in 2016. Inputs for ridesplit include base fare ($2.48/trip), mileage fee ($1.03/mile), and a time fee ($9.90/hour).

Table 2.2: SOV and Ridesplit Costs [12]

Rideshare	
Base fare ($/trip)	3.30
Mileage fee ($/mile)	1.37
Time fee ($/hour)	13.20
Ridesplit (25% discount from rideshare)	
Base fare ($/trip)	2.48
Mileage fee ($/mile)	1.03
Time fee ($/hour)	9.90

Automated rideshare costs- The cost per mile for automated vehicles was assumed to remain similar to existing rideshare costs, but discounted by 50% to account for the removal of labor costs for driverless cars (see Table 2.2). This assumption is based on a variety of conversations with transportation industry professionals[13], which range from a 50% - 80% decreased cost of operating a vehicle. Inputs for automated rideshare include base fare ($1.65/trip), mileage fee ($.69/mile), and a time fee ($6.60/hour).

11 Parking costs are estimated available data for parking in the central business district. Source: Collier International, Survey of parking rates in 156 CBD's worldwide. Accessible at: http://www.thetruthaboutcars.com/wp-content/uploads/2011/07/globalcolliersparkingratesurvey2011.pdf
12 Uber July 2016
13 ITE Annual Conference, 2016. Session: Ready or Not... Self-Driving Vehicles are Coming to a City Near You. Speaker: Wes Guckert.

Automated ridesplit costs- Ridesplit costs for automated vehicles are further reduced by 20% from automated rideshare per mile costs. The 20% reduction was utilized (as opposed to 25%), due to the already lowered estimate of base cost of automated rideshare costs. Inputs for automated ridesplit include base fare ($1.32/trip), mileage fee ($.55/mile), and a time fee ($5.28/hour).

Table 2.3: Automated Rideshare and Ridesplit Costs

Automated rideshare (50% discount from rideshare)	
Base fare ($/trip)	1.65
Mileage fee ($/mile)	0.69
Time fee ($/hour)	6.60
Automated Ridesplit (20% discount from automated rideshare)	
Base fare ($/trip)	1.32
Mileage fee ($/mile)	0.55
Time fee ($/hour)	5.28

Transit costs- The transit fare ($/trip) for the economic model is $2.75, which is the median price for a Sound Transit Link light rail trip and for a Metro transit bus ride.

Table 2.4: Transit costs

Transit	
Fare $/trip	2.75

Car share costs- The cost for car share is based on ReachNow's per minute fee of $0.49.[14] With ReachNow, a one-way car share model, users pay per-minute with mileage and time rate caps for longer trips. Round trip car share companies often charge an annual membership fee in addition to an hourly fee. Only one-way car share pricing was included in this model as the analysis is based on a per trip basis.

Table 2.5: Car share costs

Car Share (ReachNow)	
$/hr	29.40

Step 2: Determine cost of each mode as a function of annual miles driven

Using car ownership, TNC, transit, and car share cost data, the annual cost and cost per mile function for each mode was calculated as miles driven annually increases. Inputs include costs per mile and average number of trips per day15 and is calculated for a range of 250 to 15,000 VMT per year. The average number of trips per day used in the calculations below (2.6/day) is from the National Household Travel Survey for the Seattle area.[16] As there is no explicit input for trip length in this model, the model assumes those driving a greater number of miles per year are taking longer trips each day.

14 ReachNow, 2016
15 2.6 trips per day. Source: National Household Travel Survey
16 National Household Travel Survey, 2009

Personal vehicle cost per mile calculation:

SOV cost per mile by miles driven per year= (License, registration, taxes + Insurance + depreciation + financing /miles driven per year) + (fuel cost x 1 /fuel efficiency) + maintenance

Rideshare cost per mile calculation:

Rideshare cost per mile by miles driven per year= (Number of trips per day x 365 days per year x rideshare base fare) + (Miles driven per year x rideshare mileage fee) + (Miles driven per year/MPH x rideshare time fee))/miles driven per year

Figures 2.1 and 2.2 below show the annual cost and per mile cost by mode.

Figure 2.1: Annual Cost by Mode

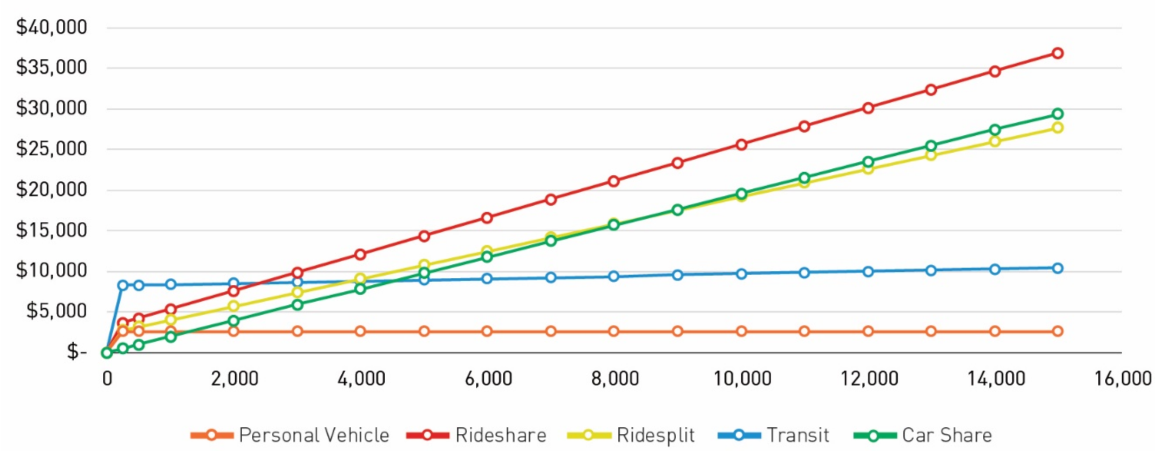
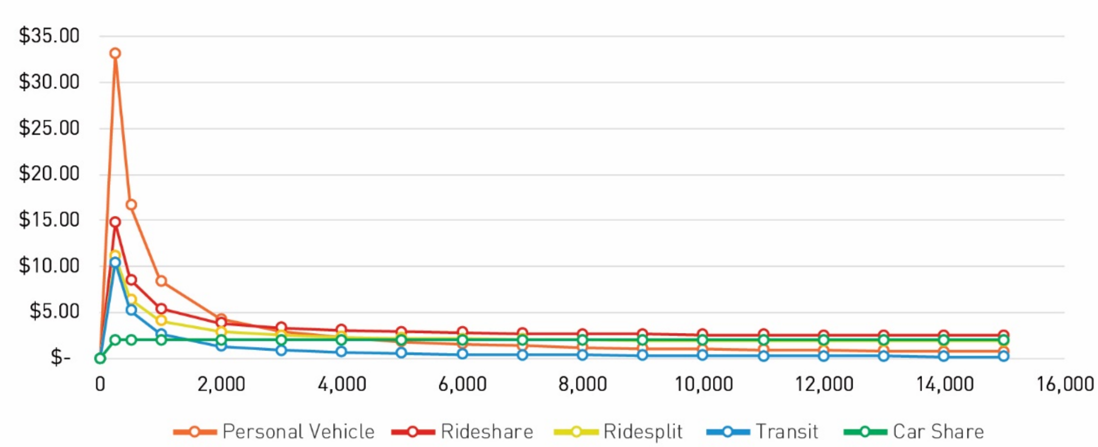


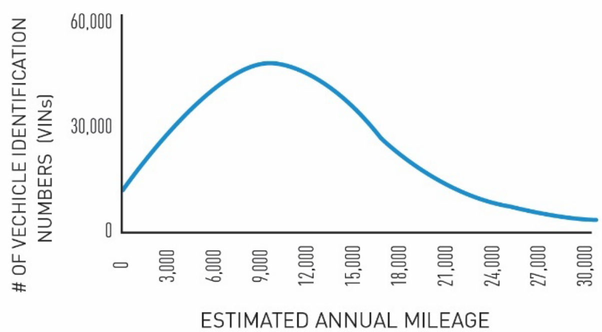
Figure 2.2: Cost per Mile by Mode



Step 3: Calculate the total number of vehicles for each geography by vehicle type.
As shown in Table 2.1, the per mile costs for personal vehicles varies by vehicle type. Using U.S. Census American Community Survey 5-year estimates, the total vehicles available for each geography was distributed into small, medium, and large sedans based on a national distribution of the car fleet.

Step 4: Determine the number of total vehicles miles traveled (VMT) below which it would be cheaper for a person to give up their personal vehicle and use shared mobility and/or transit instead (i.e. the 'breakeven point')
As exhibited in Figure 2.3, a dataset of all registered vehicles in the state of Massachusetts shows the distribution of estimated annual mileage by total number of Vehicle Identification Numbers (VINs).[17] VINs were utilized as the analysis attempts to analyze mode change by vehicle. As data were not available on the number of people who use each vehicle (i.e. a family of four sharing one vehicle), the results are calculated in the potential number of vehicles reduced, not the number of people giving up their vehicles. The model assumes that the VMT distribution is similar in King County since a comparable proportion of land use types and traffic patterns are represented. A local data source is not available with this type of VMT distribution.

Figure 2.3: Massachusetts Annual VMT

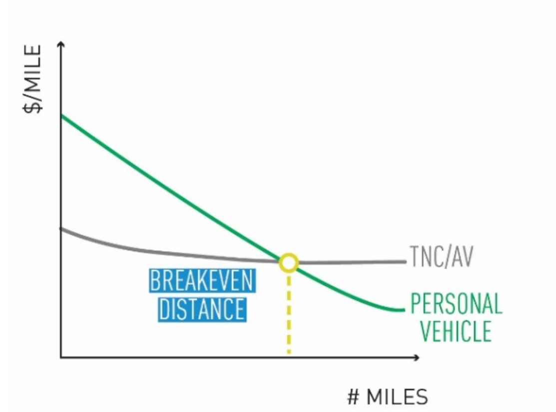


Source: Massachusetts Commonwealth Automobile Reinsurer (CAR) and the Registry of Motor Vehicles (RMV)

It is assumed that the cost of owning a personal vehicle decreases when the total number of miles driven per year increases. The 'breakeven point' is the point where annual cost by number of miles driven is equal for personal vehicles and TNCs, transit, car share, or shared automated vehicles (see Figure 2.4). Each mode has a different breakeven point and many people may use a combination of modes to replace personal vehicle miles driven. In this analysis, the breakeven point finds the total cost of vehicle ownership below which drivers would switch (i.e. vehicle shedding) to use one or more alternative modes. Those who choose not to buy a vehicle in the first place (i.e. vehicle suppression) are not explicitly captured in this analysis, but the breakeven concept still applies to their travel choices centered around cost.

17 Massachusetts Commonwealth Automobile (CAR) and the Registry of Motor Vehicles (RMV)

Figure 2.4: Breakeven Point schematic



Using this VMT distribution, the model determines the number of vehicles which have been driven the 'breakeven' number of miles or fewer. The model assumes that if a person drives the breakeven number of miles or fewer, they will choose to give up their personal vehicle in favor of a more economical shared mobility or transit option.

Step 5: Develop scenarios that include different combinations of shared mobility modes to model the potential personal vehicle reduction.

Six scenarios were selected to model a variety of transportation alternatives to personal vehicles, including combinations of rideshare, ridesplit, transit, car share, and rideshare automated vehicles (Table 2.6). Each scenario is from the perspective of the consumer and answers the question, "What is the potential for consumers to give up their personal vehicle based on the economical choice?" For example, if car owners had the option to either drive their personal vehicle or take rideshare (Scenario 1), which would they choose based on cost alone? As earlier noted, the use of an economic rationale accounts for potential vehicles shed, rather than vehicles suppressed.

Table 2.6: Economic Model Scenarios

Scenario	Alternative modes	Example
Scenario 1	Rideshare Only	Instead of using a personal vehicle for every trip, you take an Uber or Lyft
Scenario 2	50% Rideshare, 50% Ridesplit	Rather than driving your own vehicle for every trip, you order an Uber half the time and an UberPool for the rest of your trips
Scenario 3	25% Transit, 50% Rideshare 25% Ridesplit	You give up your car and take a combination of shared mobility services and transit
Scenario 4	25% Transit, 25% Rideshare 25% Ridesplit, 25% Car share	Instead of driving a personal vehicle, you use transit, TNCs, and car share
Scenario 5	Rideshare AV Only	You use a shared fleet of automated vehicles becomes available to the public through the MaaS, CAV, SAV
Scenario 6	50% AV Rideshare, 50% AV Ridesplit	Half the time you use Rideshare AV and the other half you share your AV ridesplit with at least one other person

2.3 Results

Results indicate that the break-even VMT, or the number of miles driven below which would be cheaper to not own a personal vehicle, vary from 2,400 to 10,000 depending on the scenario and vehicle profile (see Table 2.7 below). For example, in Scenario 1 it would be cheaper for a person who owns an "econobox" car and drives 2,429 miles or less per year to travel using rideshare instead.

Table 2.7: Break-Even VMT by Scenario and Vehicle Profile

Mobility Scenario	Profile A: Econobox Car	Profile B: Mid-Size Cars	Profile C: Large Vehicles (SUV or Minivan)
	Break-Even Vehicle Miles Traveled (VMT)		
1. **Rideshare Only**	2,429	3,251	3,804
2. **Rideshare and ridesplit**	3,822	4,961	5,740
3. **Transit, rideshare, and ridesplit**	4,466	4,301	5,248
4. **Transit, rideshare, ridesplit, and car share**	4,679	6,014	6,935
5. **AV Rideshare Only**	6,688	8,540	9,846
6. **AV Ridesplit Only**	7,748	9,864	10,058

Based on the breakeven points of each scenario, approximately 17-27% (see Table 2.8) of existing vehicles in King County could be reduced because it's cheaper for those drivers to choose shared mobility options. In other words, approximately 68,000 vehicles are driven less than the breakeven point calculated for Scenario 1, which amounts to 17% of the total car fleet. The personal vehicle reduction potential could be more than 100,000 vehicles in the City of Seattle and 370,000 in King County (see Table 2.8).

In addition, an Automated Vehicle (AV) shared fleet scenario showed a 31-45% reduction potential in personal vehicles. This is attributed to the potential lower consumer cost as compared to current rideshare costs. With an AV ridesplit scenario, the reduction potential reaches more than 600,000 vehicles in King County and nearly 180,000 in Seattle (see Table 2.9).

Table 2.8: Results by Scenario

Mobility Scenario	Vehicle Reduction Potential
1. **Rideshare**	16.66%
2. **Rideshare and ridesplit**	22.71%
3. **Transit, rideshare and ridesplit**	22.18%
4. **Transit, rideshare, ridesplit and car share**	27.23%
5. **Autonomous vehicle rideshare**	31.46%
6. **Autonomous vehicle ridesplit**	44.77%

Figure 2.5: Range of Potential Personal Vehicle Reduction (% of total vehicles available)

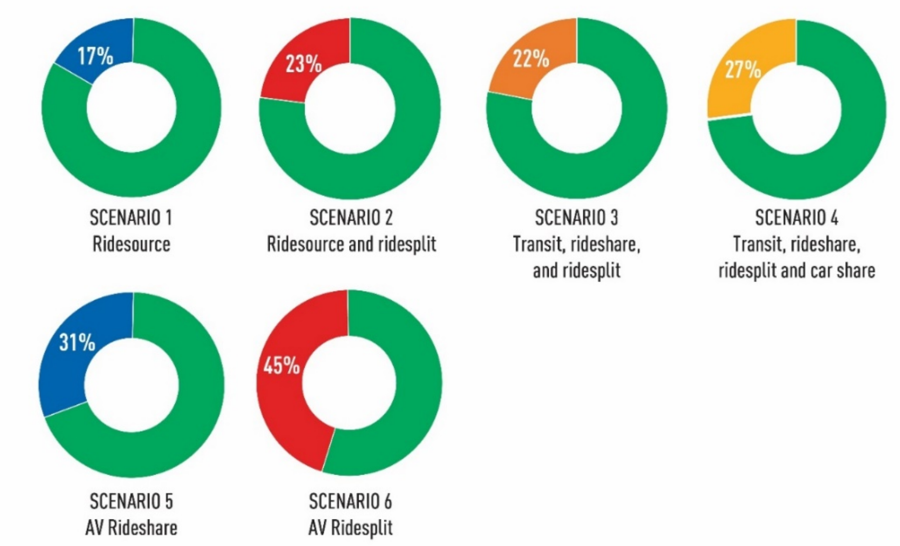


Table 2.9: Potential Vehicle Reduction by Geography

	King County	Seattle
Total Vehicles	**1,366,859**	**398,477**
Mobility scenario (% reduction)	**Potential personal vehicle reduction**	
1. Rideshare Only (17%)	227,658	66,368
2. Rideshare and Ridesplit (23%)	310,365	90,480
3. Transit, Rideshare, and ridesplit (22%)	303,160	88,380
4. Transit, Rideshare, ridesplit, and car share (27%)	372,192	108,504
5. AV Rideshare Only (31%)	429,972	123,528
6. AV Ridesplit Only (45%)	612,000	179,315

When applying the potential vehicle reduction to smaller geographies, additional constraints were added as certain areas have a lower prevalence of TNCs than others and would therefore be less likely to give up personal vehicles. Data gathered by the City of Seattle shows the number of TNC pickups from each city zip code for one quarter of 2015. Using this data, the model adjusted to ensure a more conservative vehicle reduction to the neighborhoods of Columbia City and Ballard as there was lower TNC use than in Downtown Seattle and the University District.

As shown in Table 2.10, Downtown Seattle and University District, which both have the most TNC trips, are used as a baseline. An estimated adjustment in vehicle reduction was applied to Ballard (12.5%) and Columbia City (25%) based on the portion of trips as compared to Downtown Seattle.

Table 2.10: Model adjustments for Seattle Neighborhoods

Origin neighborhood	# TNC trips	% of total	Model adjustment
Downtown	97,025	39.8%	0%
University District	85,379	35.0%	0%
Ballard	45,178	18.5%	-12.5%
Columbia City	16,045	6.6%	-25%

Note: The number of TNC trips were averaged for zip codes containing each neighborhood

Rideshare data elsewhere in King County is not currently publicly available, so population density from the U.S. Census was used to determine rideshare and SOV use as compared to the City of Seattle. It is assumed that with a lower population density, these areas may remain more auto-dependent as compared to dense urban neighborhoods or there may be a lower availability of rideshare or ridesplit services. A qualitative assessment was utilized for the suburban jurisdictions.

The results for Shoreline, an inner ring suburb, received the lowest adjustment among the suburban jurisdictions (25%) due to the proximity to the CBD and current transit network. At the other end of the spectrum, results for Maple Valley and Sammamish, exurban jurisdictions, were adjusted at an additional 50% based on land-use, proximity to CBD and other job centers and connections to the transit network. Bellevue and Kent received a 30% adjustment, more conservative than Shoreline, and higher compared to exurban jurisdictions due to the relative proximity to the transit network. The model applies an adjustment to vehicle reduction potential for each geography, as show in Table 2.11.

Table 2.11: Model Adjustments for King County Suburban Jurisdictions

Origin neighborhood	Population density	Model adjustment[18]
Sammamish	2,693.2	50%
Shoreline	4,647.4	25%
Bellevue	4,137.6	30%
Maple Valley	4,202.6	40%
Kent	4,283.6	30%

The model adjustments shown in Tables 2.10 and 2.11 were applied to the results. As shown below in Table 2.12, the potential reduction of personal vehicles varies throughout four Seattle neighborhoods and five King County jurisdictions based on total vehicles.

Table 2.12: Potential personal vehicle reduction by scenario

Area	Ballard	U-District	Columbia City	Downtown Seattle	Sammamish	Shoreline	Bellevue	Maple Valley	Kent
Total Vehicles	**15,613**	**10,125**	**7,915**	**29,358**	**33,927**	**37,811**	**89,942**	**17,079**	**76,395**
Mobility scenario	**Potential personal vehicle reduction**								
Additional adjustment for each typology	-12.5%	None	-25%	None	-50%	-25%	-30%	-40%	-30%
1. Rideshare Only (17%)	2,275	1,686	989	4,890	2,825	4,723	10,486	1,707	8,907
2. Rideshare and Ridesplit (23%)	3,102	2,299	1,348	6,666	3,852	6,439	14,296	2,327	12,143
3. Transit, Rideshare, and ridesplit (22%)	3,030	2,246	1,317	6,511	3,762	6,290	13,964	2,273	11,861
4. Transit, Rideshare, ridesplit, and car share (27%)	3,720	2,757	1,616	7,994	4,619	7,722	17,144	2,790	14,562
5. AV Rideshare Only (31%)	4,297	3,185	1,867	9,235	5,336	8,921	19,805	3,224	16,822
6. AV Ridesplit Only (45%)	6,117	4,533	2,658	13,145	7,595	12,697	28,190	4,588	23,944

These results show the number of personal vehicles that could be reduced in each Seattle neighborhood or suburban jurisdiction. As expected, the most dramatic reduction in personally-owned vehicles is in the Seattle neighborhoods. Key highlights include:

- Downtown Seattle would see nearly 8,000 SOVs (over a quarter of current vehicles) taken off the road in Scenario 4, which combines transit with shared mobility options.
- A decrease of 3,720 vehicles in Ballard, an area less than three square miles, could have major implications for available right-of-way and a shift in land uses for the City neighborhood.
- Even with conservative reduction adjustments in suburban jurisdictions, there is great potential to see a shift from privately owned vehicles to rideshare, ridesplit, transit, car share, and automated vehicles. Kent and Bellevue, suburbs with high vehicle ownership, could experience around 15,000 less SOVs (over 18%).
- When considering the larger geographic areas, King County and Seattle would experience a vehicle reduction over 370,000 and 108,000 (or 27%), respectively.

2.4 Lessons learned

- The results of this analysis indicate upper bounds of potential vehicle reduction given that lifestyle factors may make ownership necessary for some households, particularly in the suburbs.
- This model was created by compiling available data, and as such, limitations include using non-local datasets such as the Massachusetts VMT information. Due to available datasets from the U.S. Census, the potential reduction in total vehicles was performed using the count of vehicles available in each geography. Converting vehicles to people could be performed in the future, but data for this conversion was not available.
- The model, by design, only includes an economic rationale without consideration of lifestyle factors which vary by individual and household. Households with children cannot easily use carsharing or ridesharing in ways that wholly replace personal vehicles, and therefore VMT may not be the main impetus for mode choice.
- Additional factors, such as travel time, were not included in the analysis as the data sets were too limited to adequately assess the impacts. This stated, there is an assumption that rideshare travel time and customer experience would be similar to driving for many of the trip types.
- The model is limited by the inability to adequately include surge pricing. Surge pricing may impact the economic competitiveness of ridesplitting.
- The results assume the present population as fixed. However, population growth and the potential expansion of shared mobility may impact the number of total vehicles in each area.
- The model does not include a timeframe for vehicle reduction. People may decide to shift to a car-free lifestyle when opportunities – such as at the end of a car lease – present themselves. The model shows the trade-off from an economic perspective which will result as major purchasing or life decisions are made by individual car-owners
- Induced demand of shared modes could change the cost of these services and needs to be considered if utilizing this analysis in the future.

2.5 Policy Implications

- The reduction in vehicles and mode shift will have implications for personal parking reduction, parking requirement for new development, and street parking supply. These implications will be even more apparent after the implementation of ST3, Metro Connects, and Move Seattle.
- Vehicle ownership reduction in the range of 17 to 27% will have dramatic impacts on both on-street and off-street parking requirements. With regard to on-street parking, the potential to add transit-only lanes, cycling infrastructure, and pedestrian improvements is expected to appear as the parking demand is diminished. A full analysis of parking demand reduction is also identified in Chapter 5 of this report.
- Integrating shared mobility with transit could escalate vehicle shedding up to 27%. A true Mobility as a Service (MaaS) network, currently being adopted in Northern Europe and the United Arab Emirates, provides a potential benefit of an additional vehicle reduction. This would increase as future transit improvements (ST3 and Metro Connects) are implemented in the region.
- The potential reduction in household transportation costs through the use of transit and ridesplit services could impact the distribution of equity in the region. Currently ridesplit services such as UberPool and Lyft Line are available throughout many areas of Seattle and King County. However, demographics such as population density may impact the use of ridesplit services in

different geographies. Policies to balance the availability of these lower-cost services should be pursued to provide additional low-cost options to areas that would see the greatest economic benefit.

- Suburban jurisdictions with high vehicle ownership (i.e. Kent and Bellevue) should consider partnerships with TNCs to provide a regional last-mile solution where gaps in transit service exist or certain demographics may be attracted to a transit-to-ridesource trip as opposed to a two-seat transit trip.

Chapter 3: PSRC Travel Demand Model

3.1 Model Logic

Travel demand models calculate the expected demand for transportation facilities by modeling population and employment data as well as roadway and transit networks to estimate daily travel patterns in a region or city. Travel-demand models allow for planners and policy makers to understand what the transportation network (i.e. capacity, traffic flows) will look like in the future with population and employment change, transportation infrastructure or service improvements, or the introduction of new modes.

The **Puget Sound Regional Council (PSRC) Travel Demand Model** was recalibrated for this report to understand the upper bounds of shared mobility's effects on mode choice and vehicle miles traveled. As shared mobility modes were not included in PSRC's most recent travel demand model, this exercise sought to integrate shared mobility data with PSRC's four-step travel demand model to more accurately determine the future of mobility within the region.

The project team collaborated with and provided input to PSRC to perform over twenty model runs, the results of which are introduced in this chapter. The model iterations intended to produce results that showed potential impacts to travel behavior that new shared mobility and imminent automated vehicles will have on the region. However, the results in early runs were problematic as the travel demand model was re-assigning very few trips to new shared mobility modes. This was because at the time of the survey, TNCs were not yet a mobility option and were therefore not reflected in the results of the survey. This stated, the solution included utilizing the results of the economic model (see Chapter 2) as inputs in the travel demand model. The model was run in scenarios where 25% and 50% of people shifted behavior and gave up their cars. These inputs were modeled for the 2030 horizon year matched with price-point options for TNCs and resulted in a major shift in mode choice.

A reduction of auto-ownership of 25% and 50% were used as inputs for the model runs and are not policy goals of SDOT or Metro. These numbers were reflective of staff input, the range of outputs from the economic model in Chapter 2, and identify a dramatic shift in current mode share. These are inputs to identify potential transportation impacts if there were to be a dramatic shift to shared mobility services and automated vehicles. These percentage reductions should not be interpreted as mode shift goals. A full breakdown of this process and results are described in the following section.

3.2 Methodology and Assumptions

According to PSRC, "For every household in the region, the model estimates how many trips are made each day, where they go, what time of day they travel, which modes they use, and which routes they follow. The relationships that are estimated for the base year are combined with future population, employment, and transportation infrastructure growth assumptions to produce future travel forecasts. The future travel forecasts are then analyzed to inform regional transportation studies and plans."[19]

The travel model was built from the Puget Sound Household Travel Survey conducted in 2006 and adjusted with 2014 survey data. Working with the City of Seattle, PSRC sampled 6,000 households in the region on travel behavior. The surveys, along with traffic counts, transit boarding, and Census data, were considered to determine current travel behavior in a holistic model for the Seattle Region. This model can measure impacts of transportation improvements and provide outputs such as VMT, changes in mode share, and other metrics that inform decision-making for potential transportation improvements.

19 PSRC. Trip Based Travel Model. Available at: http://www.psrc.org/data/models/trip-based-travel-model/

Background Assumptions
For this analysis, the model assumed a forecast year of 2030. For the network assumptions, it assumed the buildout of ST3 and Metro Connects[20] as well as the region's Transportation 2040 Long Range Plan. The 2030 Land Use is based on PSRC's Land Use Vision data product.

There are four primary components as part of the four-step modeling process[21]:

Trip generation: *The trip generation models estimate the number of trips produced and attracted to each of the Traffic Analysis Zones (TAZs) in the model system. A TAZ is a geographic boundary used to assess transportation patterns in transportation planning models. There are approximately 4,000 TAZs in the Seattle Region based upon homogeneous land uses, connections to transportation infrastructure, and other demographic factors. The trips produced are estimated from households and their socioeconomic characteristics. The trips attracted are estimated from employment categorized by type.*

Trip distribution: *The trip distribution models estimate the number of trips from each TAZ to each other TAZ. This is performed by gravity models that utilize transportation costs, travel time, and other factors to determine the travel between TAZs.*

Mode choice: *Productions and attractions of the trip generation model are linked in trip distribution, creating zone-to-zone person-trip movements. These trips are then apportioned to the available travel modes through the application of the mode choice model.*

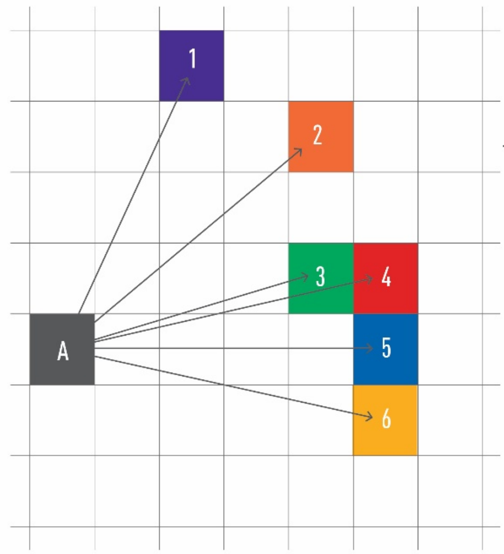
Trip assignment: *The trip assignment model estimates the volume on each link in the transportation system for both highway and transit modes. In addition, the trip assignment model generates specific performance measures, such as the congested speed or travel time on a highway link or the boardings and alightings on a transit route. Trip assignment is performed separately for each mode (auto and transit) and time period (am peak, midday, pm peak, evening, and night).*

With rapidly changing transportation options it can prove difficult to accurately reflect true travel behavior. In 2006, car share was in its beginning stages and shared mobility had a very small presence overall. In order to include shared mobility in the PSRC model, the model used an approach to include the cost of shared mobility as well as transit and single-occupancy vehicles.

20 Sound Transit 3 will add 62 miles of new light rail for a total of 116 miles serving 3.7 million future residents of the Seattle Region. Metro Connects will increase Metro service by 70 percent, thereby introducing an additional 2.5 million new service hours to Metro service by 2040.
21 Text from PSRC Travel Model Documentation Final Report (2007) and Puget Sound 4K Model Version 4.0.3 (2015). Available at http://www.psrc.org/assets/1511/model_doc_final_.pdf and
http://www.psrc.org/assets/12593/4kModelDocumentation4.0.3.pdf

Step 1: Calculate travel demand between each TAZ (traffic analysis zone)

Figure 3.1: Travel demand



Origin/ Destination Pair	Trips
A1	7
A2	12
A3	3
A4	10
A5	6
A6	15

The PSRC model calculated travel demand between each traffic analysis zone, including the total number of trips for each origin and destination pair.

Step 2: Calculate total cost ("disutility") by mode

Total cost is a combination of factors which varies by mode. A wide range of cost variables are incorporated into total costs, an example of which is shown below:

$$\textit{Total Cost}_{\_SOV} = \beta(\textit{driving time}) + \beta(\textit{fuel cost}) + \beta(\textit{parking price})$$

$$\textit{Total Cost}_{\_TRANSIT} = \beta(\textit{waiting time}) + \beta(\textit{in-vehicle time}) + \beta(\textit{fare})$$

"β" is a parameter calculated by PSRC that modifies the impact each variable has on the total cost
For TNC, TNC pool, and Microtransit, we estimated β based on current shared mobility costs.

Step 3: Estimate mode share

The mode share is calculated as:

$$\textit{Mode Share}_{\_SOV} = \textit{Total Cost}_{\_SOV} \div \textit{sum of total cost of all other modes}$$

Step 4: Calibrate β parameters using magnitude of shared mobility data and updated 2014 results

Using the magnitude of shared mobility trips per quarter gleaned from SDOT's TNC data, initial outputs of the model were calibrated to reflect realistic figures.

These calibration runs were tested on PSRC's 2014 model, which included updates to the 2006 model. However, when the model was initially run to determine future mode share with shared mobility included, the resulting outputs were found to be less sensitive than was expected to changes in the input parameters. Since the PSRC model uses a car ownership sub-model based on 2006 survey data, there is an over-reliance on personal vehicle use. The model revealed that auto ownership was completely tied to demographics and that certain household income levels always returned high auto ownership levels. Although zero-car households were once an indicator of socio-economic status, it is no longer an absolute indicator, as people now voluntarily decide to sell their vehicle or not buy one in the first place for reasons other than cost alone.

To overcome this bias, the model was run with two personal vehicle reduction inputs:

1. 25% personal vehicle reduction in 2030
2. 50% personal vehicle reduction in 2030

In this model, personal vehicle reduction is not a goal or result, but rather an input from the results of the economic model (Chapter 2). Challenges that stem from this approach include that mode share outputs may be overestimated for 2030 if a high rate of vehicle reduction does not occur. However, using these inputs, the model was found to be more sensitive to changes and other variables, which included Sound Transit 3 (the regional transit expansion plan) and Metro Connects (Metro's long-range transit plan). Both have the potential to be influential factors that change the mode share of auto ownership and shared mobility.

Observations in the City of Seattle reveal the share of transit and shared mobility has been increasing due to a reduction in HOV and SOV share but also from an increase in the share of walking and biking. As our regional and urban centers grow and our active transportation networks continue to expand, the biking and walking mode share is predicted to grow. To account for the predicted increase in biking and walking mode share, the model was post-processed to retain both walk and bike trips and eliminate any transit-walk bias that is often not reflected in regional travel demand models. Two main findings resulted from multiple model iterations. First, the model found that the 2014 bike and walk mode share was being undercounted, which was consequently resolved by making post-process adjustments to raise the 2014 share as well as increase it in the 2030 scenarios. The second involved keeping non-motorized mode share at the same level for each 2030 scenario. The presence of shared mobility does not indicate that bike mode share would decrease. Adjustments were made based on observations from the household survey at the regional level and applied to all geographies.

Commute Seattle Center City Mode Split Survey

Separate from the travel survey conducted by PSRC, Commute Seattle, a not-for-profit Transportation Management Association (TMA), conducts a survey every two years to understand how commuters travel downtown.[22] The study surveys commuters traveling to worksites located in Seattle's Center City to measure mode share in the morning peak hours. The study combines 2016 mode-split study with data from Washington State Department of Transportation's (WSDOT's) survey of employees at larger Seattle Center City businesses affected by the State of Washington's Commute Trip Reduction (CTR) Efficiency Act.

This Commute Seattle Center City Survey is not representative of the entire City of Seattle or King County because it is biased towards downtown Seattle and morning commuters. As a result, transit, walk, and bike mode split in the Commute Seattle Survey is higher than the PSRC results. The Commute Seattle survey should be considered in conjunction with PSRC results, but cannot be calibrated in this exercise.

3.3 Results

Key results of the model included the following:

- With a 25% reduction of personal vehicle ownership, the City of Seattle could see 85,000 less SOV trips each day, a 4.4% decrease from 2014 daily trips. King County (including Seattle) could experience 220,000 less daily SOV trips and 350,000 less trips in the Region overall.

22 2016 Center City Commuter Mode Split Survey. Available at: https://commuteseattle.com/wp-content/uploads/2017/02/2016-Mode-Split-Report-FINAL.pdf

- With a 50% reduction of personal vehicles, the model results indicate 240,000 less daily SOV trips. Similarly, King County (including Seattle) could see 870,000 less trips with SOV trips potentially reduced by 420,000 in the entire Region.
- Results indicate that shared mobility mode share could increase from 1% of all trips in the Region (2014) to 10-13% of daily trips.
- The model also predicts in increase in transit mode share. While transit is currently 3% of regional daily trips, a 25% and 50% reduction in personal vehicles could see 7% and 11% daily transit mode shares, respectively.
- The model suggests that in 2030, there will be 3% to 4% more transit trips in the AM peak as compared to the PM peak.
- The results suggest an increase in transit and shared mobility at the same time, suggesting shared mobility will not necessarily decrease transit mode share or even compete with fixed-route transit service.

Table 3.1: Regional Mode Share: 2014 to 2030

Daily Mode Share	2014 Regional Daily Mode Shares	2030 Regional Daily Mode Shares: Auto Ownership reduced 25%	2030 Regional Daily Mode Shares: Auto Ownership reduced 50%
Daily Trips	15,489,742	19,818,490	19,818,490
Trips by personal vehicle	86%	72%	65%
trips by personal vehicle: SOV	44%	36%	32%
trips by personal vehicle: HOV	43%	36%	33%
% trips by transit	3%	7%	11%
% trips by walk and bike	10%	11%	11%
% trips by shared mobility	1%	10%	13%

The results are exhibited below in Figure 3.2 and 3.3 the study areas with addition information available in the typology appendix.

Figure 3.2 Seattle typology results

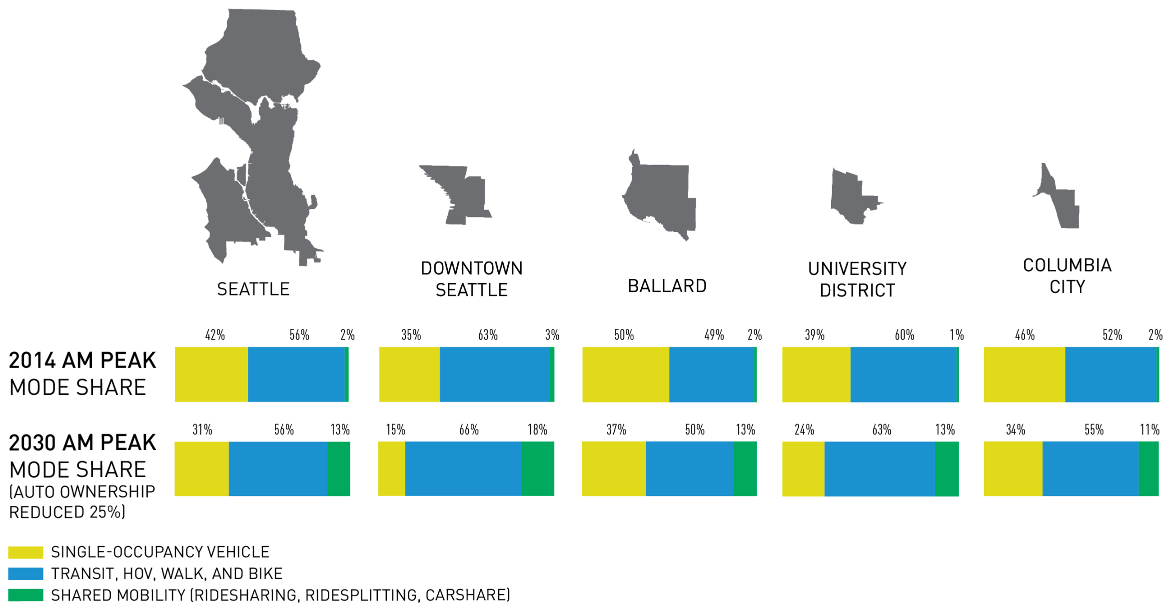
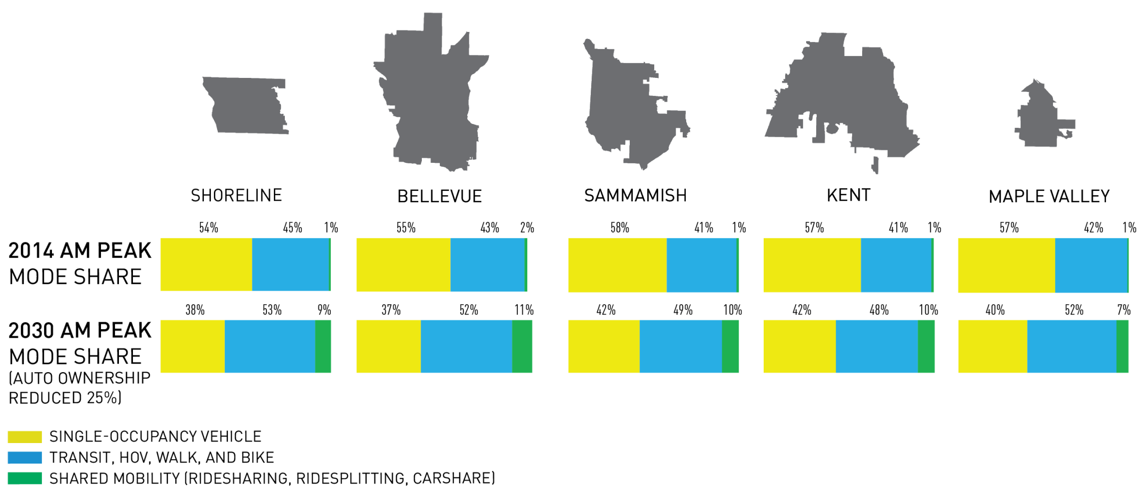


Figure 3.3 King County typology results



3.4 Lessons Learned

- Planners and academics are beginning to model shared modes into travel demand models and other analyses.[23] Limitations exist, as in this analysis, where shared mobility is not included in the travel-demand survey or as a coefficient along with other modes. Our expectations were always that the PSRC Travel Demand Model would be utilized to supplement findings from the other models that were created in this project (as opposed to being utilized for decision-making on its own).

23 Ciari, F., Balac, M., Axhausen, K. W. *Modeling carsharing with the agent-based simulation MATSim: state of the art, applications and future developments*, accepted for publication in Transportation Research Record, 2016.

- A reduction of auto-ownership of 25% and 50% were used as baselines for the model runs. These percentage reductions should not be interpreted as mode shift goals for the City or the County. These numbers were reflective of the range of outputs from the economic model in Chapter 2. This is an academic exercise and therefore, these percentage reductions should not be interpreted as mode shift goals.
- The Travel Demand Model (and every Travel Demand Model) is most useful in identifying impacts and trends on a regional basis. The model is not as useful in predictions on a neighborhood scale. Our team was aware of these limitations up front and understood this is a starting point for analyzing impacts on a smaller scale.
- The Travel Demand Model is limited in assessing changing attitudes related to the value of car ownership. The survey results utilized in the model were conducted in 2006; at a time where shared mobility options were not included in the survey or in operation in the Seattle Region. This stated, producing useful results for this exercise was not feasible without changing the inputs to the model and reducing auto ownership. Additional data is needed from subsequent surveys taken in the future to analyze these future trends and questions related to shared mobility usage are imperative. A 2017 travel survey is currently underway and the PSRC model will be updated with this information.
- The Commute Seattle survey results can be used in conjunction with PSRC survey results to understand Seattle Center City mode split and how it may vary if Mobility as a Service is integrated into Seattle's transportation system.
- The activity-based model, currently in development by PSRC, would provide more accurate and sophisticated results. Activity- based models more accurately replicate traveler decisions than travel demand models, as they predict how people plan and schedule their daily travel.[24] SDOT and King County Metro should work with PSRC to utilize this model for future modeling activities of this kind. The intent of utilizing the Travel Demand Model was to identify trends and broad-level results. As behaviors and conditions continue to change, receiving and updating information in the activity based model with survey data gathered every two years as opposed to six to eight years is vital for tool accuracy.

3.5 Policy Implications

- Results of this analysis can be utilized for decision-making related to integrating shared mobility into the transportation system, optimizing the public right-of-way, and making shared mobility equitable to all. All geographic regions in King County will experience major impacts on parking demand, mode share, transit ridership, and decreased vehicle ownership.
- This would allow for major overhauls in right-of-way design, transit deployment, and an explosion in shared mobility options. These significant changes would also impact demand for street parking and private parking and would help achieve mode share goals set by the Commute Trip Reduction Program and local cities.
- For smaller neighborhoods and suburban jurisdictions, the changes would also be significant, allowing for more pedestrian space in residential districts and commercial nodes.
  An increase of shared mobility, transit, walking, and biking mode shares should be planned for with integrated shared mobility hubs throughout the study areas to further increase accessibility and use of these transportation options.
- Induced demand of shared mobility could affect mode share in 2030, which may not be reflected in the model's results.

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24 Transportation Research Board (2015). Activity-Based Travel Demand Models. Available at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_C46.pdf

- While SOV trips are modeled to decrease by 2030, the number of miles driven by shared mobility vehicles should be considered when creating transportation policies, potentially by encouraging high-occupancy microtransit or ridesplitting.

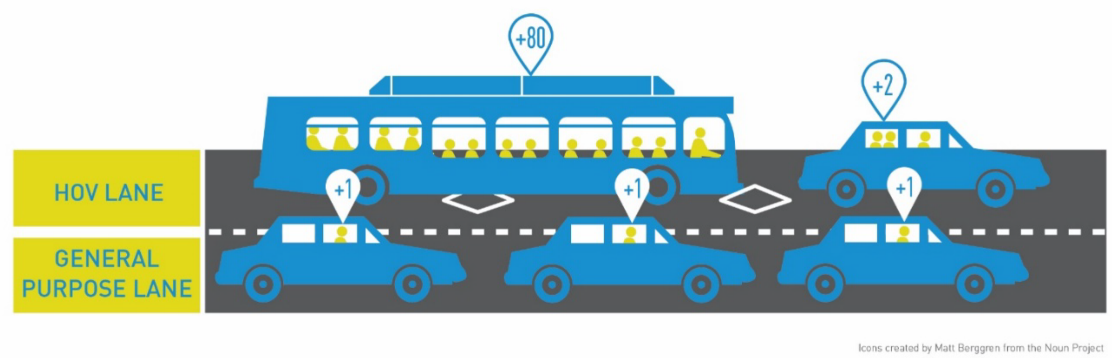
Chapter 4: Right-of-Way Capacity and HOVe Model

4.1 Model Logic

Transit is by far the most effective tool to increase the people throughput capacity of a given roadway. However, new transit service and infrastructure is not feasible in all locations and can't serve all origin-destination pairs. Carpooling has shown great promise to potentially reduce congestion and increase people throughput. However, the goal to match drivers and riders at a large scale has never been achieved. Ridesplit trips have the potential to significantly increase the average occupancy of vehicles on King County's roadways. One method to measure the occupancy of vehicles on a roadway is by calculating high-occupancy vehicle efficiency (HOVe). The higher the HOVe, the more efficient the people throughput of a street is. In other words, an increase in HOVe means cities can move more people with less vehicles, which could result in decreased congestion and pollution levels.

The Capacity Analysis first looks at the people throughput implications of different levels of transit service on a typical two lane Seattle street. The output of the model shows how HOVe, or number of people per vehicle, increases by adding high-occupancy vehicle (HOV) shared mobility options, HOV lanes and/or transit only lanes, and increasing bus frequency.

Figure 4.1 HOV and general purpose lanes



4.2 Methodology and Assumptions

Inputs of the model include varying levels of bus frequency, passengers per bus, cars per lane, people per single-occupancy vehicle (SOV) or rideshare vehicle/taxi, and total people throughput.

Table 4.1: Model Inputs and Assumptions[25]

Input	Value
Bus frequency	Every 1 to 20 minutes
Passengers per bus	80 people
Cars per lane per hour	800 cars
People per SOV	1.2 people

25 Inputs for each mode are based on assumptions and/or estimates and can be altered to model different vehicle capacities.

People per rideshare vehicle or taxi/for-hire	2 people
People per microtransit vehicle	15 people

The Capacity Model makes assumptions about the number of people traveling in each vehicle type, all of which can be manipulated to understand how a change in occupancy increases or decreases HOVe. The level of transit service ranges from 1 minute to 20 minute headways and the model assumes a capacity of 80 people per 60-foot bus. In the King County region, personally owned vehicles carry 1.2 passengers on average per the PSRC regional model. The model assumes that the typical lane carries 800 cars per hour at full capacity. For rideshare or taxi, it assumes 2 people per vehicle (in addition to the driver) and 15 people per microtransit vehicle.

Step 1: Establish different mode split and dedicated lane scenarios

The model uses four different roadway scenarios to determine HOVe under different transit and ridesplit constraints:

Table 4.2: Description of scenarios

Scenario	Description
Scenario 1	Two general purpose lanes
Scenario 2	One general purpose lane + one transit-only lane
Scenario 3	One general purpose lane + one transit and ridesplit only lane (HOV3)
Scenario 4	One general purpose lane + one transit and microtransit only lane (HOV10)

Step 2: Calculate number of people per vehicle in general purpose lanes

HOVe is the *number of people per vehicle per hour* traveling on a street, so the main inputs are the occupancy of each vehicle type.

People in buses = buses per hour x people per bus
+ People in single-occupancy vehicles = vehicles per lane per hour x people per vehicle
+ People in rideshare vehicles = vehicles per lane per hour x people per vehicle

= total people traveling on roadway

Step 3: Calculate number of people per vehicle in transit and rideshare dedicated lanes

In Scenario 1, single-occupancy vehicles and buses travel in two general purpose lanes, which means there are 800 vehicles per lane (1,600 total) with buses. This scenario also explores how HOVe changes when 25% of SOVs are replaced with higher occupancy taxi or ridesplit vehicles. Scenarios 2 through 4 examine how HOVe changes with lanes dedicated to high occupancy vehicles. In Scenario 2, SOVs and ridesplit vehicles only travel in one lane (800 cars total) and buses run at various headways in their own lane free from car traffic.

Scenario 3 introduces ridesplit vehicles into the dedicated lane. In this situation, the model accounts for the space each vehicle type takes up in the lane to ensure buses are not slowed by other vehicles and retain a high level of service. It assumes that each bus takes up 60-feet, each rideshare vehicle uses 20-

feet, and each microtransit vehicle uses 35-feet. For example, if there are 6 buses per hour occupying 360 feet, the number of rideshare vehicles must decrease from 800 vehicles per lane to allow a high-level of transit service.

800 vehicles per lane per hour   **- (Number of buses x 60 feet)/ (Space used by each vehicle)**   **= total ridesplit vehicles that can use the bus lane and maintain a high level of service**

Step 4: Calculate HOVe

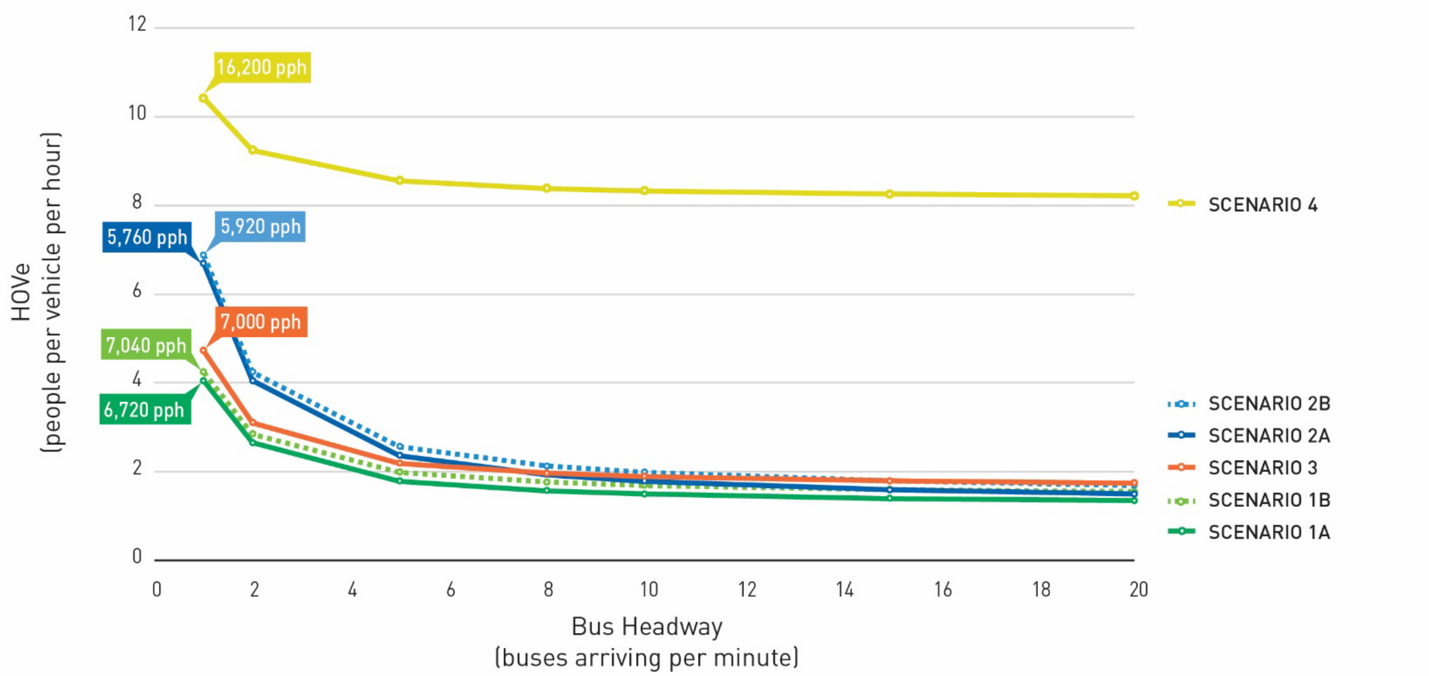
To find the HOVe for each scenario, the total number of people traveling in single-occupancy vehicles, transit, rideshare vehicles and microtransit is divided by the total number of vehicles.

HOVe= total people traveling on roadway/ total vehicles

4.3 Results

The following results show the HOVe of a two-lane roadway for each scenario and all inputs.

Figure 4.2: HOVe by Scenario



In scenario 1, a roadway with two general purpose lanes with single-occupancy vehicles and buses can reach an HOVe of 4.05 people with a frequency of one bus per minute. HOVe decreases to less than 2 people per vehicle when bus headways are every five minutes or more. When replacing 25% of single-occupancy vehicles with ridesplit in Scenario 1B, HOVe can reach 4.25 people per vehicle. In this scenario, the increases in HOVe with ridesplit are minimal because while there are 320 more people per hour traveling on the road, there are the same number of cars.

In scenario 2, a bus only lane with only SOVs only in the second lane can produce an HOVe of 6.7 with bus headways every minute. Replacing 25% of SOVs with ridesplit can increase HOVe to almost 77 people per vehicle (Scenario 2B). As with the previous scenario, there are marginal gains in HOVe when replacing 25% of SOVs with ridesplit. When bus headways are every 10 minutes or greater, the use of a bus-only lane will not increase HOVe beyond 2 people per vehicle. In this case, the bus lane will be unoccupied for most of the time and an inefficient use of roadway.

A comparison of scenarios 3 and 4 shows the potential of dedicated HOV lanes to have an effect on HOVe. In scenario 3, ridesplit vehicles and buses share one dedicated lane. With one minute bus headways, this allows for more than 7,000 people to travel through the corridor in one hour in 60 buses and 1,420 vehicles. However, this scenario allows for more cars (both SOV and ridesplit) than scenarios 1 and 2, and therefore HOVe is lower at similar headways.

Scenario 4 shows the greatest potential to move more people efficiently through a corridor. With 1 minute bus headways and microtransit vehicles at full capacity, vehicles carry more than 16,000 people and HOVe reaches more than 10 people per vehicle. With this many people in high capacity vehicles, HOVe changes minimally as bus service becomes less frequent.

4.4 Lessons Learned

- This is intended to be a theoretical exercise. Additional details are needed to perform this analysis on corridor-specific projects. Considerations for traffic, varied bus capacity, pick-up/drop-off implications, capacity of street with protected bike lanes, and other infrastructure and operational issues will need to be investigated prior to any specific recommendations are made.
- This analysis does not set a cap on total demand in the corridor. Instead, it shows the potential for higher HOVe if the demand existed to fill buses at 1, 2, or 5 minute headways or enough ridesplit vehicles to warrant a separated lane. The change in optimization to reach these levels of HOVe may not be possible on roadways without the demand to fill buses at such frequent headways.
- Induced demand of shared mobility should be considered in future analyses, especially in the context of HOV lanes. If the supply of shared mobility vehicles increase, lanes reserved for transit and ridesplit vehicles could experience congestion.
- Delays specific to pick-up/drop-off activity were not included in the model and would vary depending on roadway facilities and land use types with varying levels of peak demands. There is a possibility that pick-up/drop-off activity could decrease person throughput if it contributes to congestion. A more detailed analysis including delays and issues associated with queuing is required when assessing HOVe and future re-designation of the roadway.
- Variables for automated vehicles, including potential for reduction in vehicle size, potential vehicle-chaining, and other efficiencies that would increase HOVe were not included in this analysis. Other variables for automated vehicles, including potential decrease throughput at intersections, that would decrease HOVe were also not included in this analysis. The choice not to include these potential impacts was due to the lack of significant testing at the network-level and unavailability of necessary data. It is recommended that these inputs are included when such data is available.

- This analysis did not consider TNC deadheading, which occurs when a driver is traveling to pick up a passenger or driving around waiting for a ride request. If deadheading were incorporated in future analyses, it could more accurately reflect the people throughput of a corridor.
- This analysis could be utilized in conjunction with the capacity model to create high capacity corridors in places where current street parking spaces may no longer be required.

4.5 Policy Implications

- Assessing HOVe of specific corridors or corridor typologies could be a useful method to help implement aspects of the Transit Master Plan, Metro Connects, RapidRide Expansion, and Move Seattle. As exhibited by this analysis, the power of transit to move the masses will not be replaced by shared mobility options on congested corridors, and transit should therefore continue to be the top priority for increasing mobility and equitable access.
- Further study regarding utilization of transit-only lanes to include ridesplitting and microtransit outside of the CBD should be pursued. The analysis shows that HOV shared mobility options can be utilized to supplement the optimization power of transit, providing an HOVe of 19.8 when combined with microtransit (scenario 4). This speaks to the excess capacity on a dedicated bus lane, similar to the way many HOV highway lanes are implemented to increase people throughput. Further analysis is required to identify operational, enforcement, and pick-up and drop-off issues.
- While the efficiency of vehicle capacity may be a desired policy, a capacity maximizing policy in environments in which buses cannot meet the travel demand may be destructive to capacity and likely wasteful in fuel, emissions, and cost. Policies to increase HOVe of a roadway must be based on current and predicted demand.
- Corridors suitable for higher HOVe could be prioritized as locations to implement shared mobility hubs to work towards MaaS.
- HOVe could be used for policy goal setting at a multitude of different levels, including block-level, roadway-section level, neighborhood-level, city-level, and region-wide. The HOVe could be utilized as a tool for future goal-setting, just as carbon emissions goal-setting is prevalent throughout the world in identifying benchmarks for climate goals.
- HOVe will differ depending on roadway type as it depends on the number of vehicles per hour, types of vehicles, and number of lanes. A highway with four lanes, no buses, and predominantly SOVs would have a lower HOVe than a local road with frequent bus service.

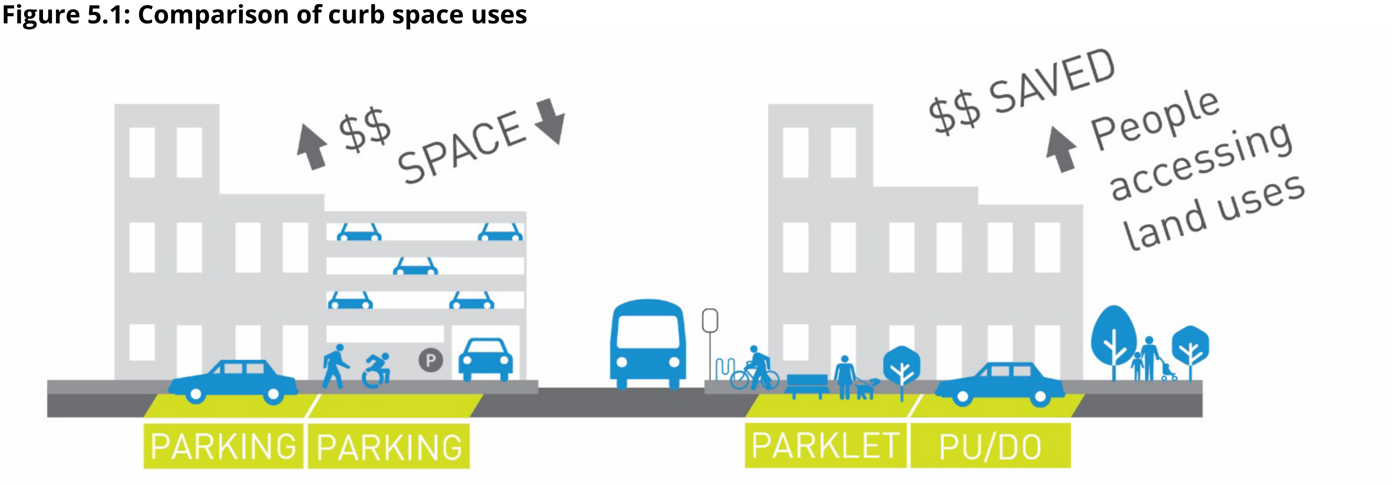
Chapter 5: Spatial Drop-Off Model

5.1 Model Logic

To plan for a transition from excessive space dedicated to parking to more pick-up and drop-off spaces for rideshare and ridesplit vehicles and taxis, we need to consider: **built form** (on- and off-street parking supply) and **activity pattern** (intensity of arrival and departure demand). Parking is a costly and an inefficient use of space, especially in urban settings. Being driven (or driverless transport) takes less space than a parking-based transportation model since we are only accommodating the interstitial activity of getting in and out of the vehicle at the destination – not storing the vehicle itself for the duration of the activity at the destination. Rideshare or automated vehicles do, however, use roadway space when traveling to pick up a passenger or when waiting for a ride request (e.g. deadheading). Nonetheless, whereas drop-off activity is measured in tens of seconds, parking turnover is typically measured in hours.

The Spatial Drop-Off model was used to analyze the pick-up and drop-off space needed for different land uses depending on the number of trips occurring during the peak period. This model does not suggest replacing the entire parking supply with pick-up/drop-off areas, as there will always be some need for parking. Rather, it acts as a tool for determining curb space demand depending on the land use. The outputs of this model are an estimated total number of pick-up and drop-off for different urban and suburban typologies. Parking supply for each land use is provided for a point of comparison, but is not an input for this model, as determining parking demand and trip demand are not synonymous methodologies.

Figure 5.1: Comparison of curb space uses



5.2 Methodology and Assumptions

Step 1: Determine number of trips per hour for each land use

Using the Institute of Transportation Engineers (ITE) Trip Generation Manual[26], the number of peak trips per hour was determined for a variety of land uses, including residential, office, commercial, and institutional. ITE trip generation rates are determined by observations and studies, many of which are carried out in suburban environments. Each land use type generates a different number of trips per hour, based on factors such as square footage or number of units.

26 Institute of Transportation Engineers (ITE). Trip Generation Manual, 9th Edition (2012).

For example, in the morning peak period, a coffee shop generates around 65 trips per hour while an elementary school generates 520 trips. Some land uses see a sharp peak in trips at a certain time of day while others have more constant trip arrival. The trip generation rate informs the number of pick-up and drop-off spaces needed for each land use. This analysis assumes that the number of trips generated by each land use are filled by ridesource or rideshare vehicles. While this concept does not match current estimates of shared mobility mode share, it serves as a methodology to understand the space needed to accommodate shared mobility in the future.

Step 2: Calculate average pick-up and drop-off time

Using an assumption of 45 seconds per pick-up/drop-off[27], a peak hour loading zone requirement was determined for each typology.

1 hour / 45 seconds (time needed for each pick-up or drop-off)

= 80 pick-up drop offs per space

Step 3: Estimate the number of pick-up and drop-off spaces needed for each land u

Trip generation rates used in the model are based on an average morning peak-hour trip rate per 1,000 square feet or number of units, in the case of apartment buildings and hotels. To find the activity level (peak trips per hour), the square footage is divided by 1,000 and multiplied by the ITE trip rate.

Activity level = (Square footage/ 1,000) x ITE trip rate

To calculate the pick-up/drop-off spaces needed for each land use, the activity level is divided by 80.

Pick-up/drop off spaces needed = Activity level/80

Example: Single Family Home

2,500 square feet/ 1,000= 2.5
2.5 x .77 = 1.93
1.93/80 = .024
Rounded to 1 pick-up drop-off space per single-family home

The main assumption for this model is there is a constant rate of arrival for peak trips. It assumes that the 45 second pick-up and drop-offs are occurring in succession throughout the hour and therefore does not account for potential queuing as a result of many arrivals or departures occurring at the same time.

For this model, all land uses were assigned an average square footage, which realistically differ depending on urban and suburban typologies.

Step 4: Estimate parking supply for comparison

The parking supply for each land use provides a point of comparison for the estimated pick-up and drop-off spaces needed for each land use. For example, a medical office may have more than 200 spaces, but with only 40 trips arrivals per hour, could be accommodated by far fewer curbside pick-up and drop-off areas. While this model does not suggest replacing 100% of the parking supply with 100% shared mobility

27 This input is based on observed pick-up and drop-off times for shared mobility services. It can be made more conservative to accommodate different land uses or urban forms.

space, understanding the maximum space needed provides context to the pick-up and drop-off space estimates.

The parking supply ratio is estimated by applying the average peak period parking demand ratio specified in the ITE Parking Generation Manual, Volume 4[28] and the square footage (or unit) associated with each land use. Similar to trip generation rates, the average peak period demand ratio is derived from surveys completed in a variety of urban and suburban locations that may not reflect the unique travel/parking demand patterns in the Seattle Region.

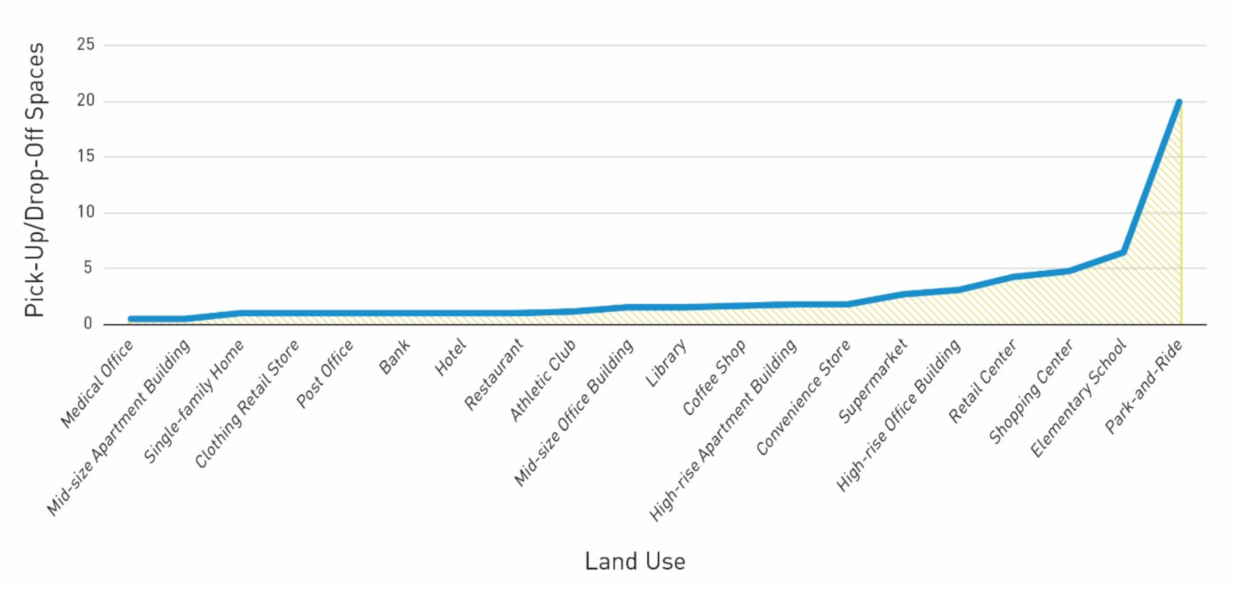
The per unit ITE average peak period parking demand ratio is multiplied by the number of units or square footage (per 1,000) to calculate the average parking supply of each land use.

Per unit parking supply ratio/units or 1,000 sqft = Average parking supply

5.3 Results

Table 5.1 shows the morning peak-hour trip generation rate, resulting activity level, and pick-up/drop off spaces needed per hour. The number of spaces is rounded in the last column to account for results which are less than 1 space. The parking supply is provided for a point of comparison. Figure 5.1 exhibits the range of spaces needed for typical land uses found in an urban/suburban area.

Figure 5.2: Pick-up and drop-off space required for each land use



28 Institute of Transportation Engineers (ITE). Parking Generation Manual (4th Edition), 2010. Available at: http://www.ite.org/tripgeneration/parking.asp

Table 5.1: Inputs used to calculate pick-up and drop-off spaces for each land use

Land Use	Sq. Feet	Units	ITE Trip generation[55]	Activity Level (peak trips/hour)	Pick-up/drop-of spaces needed per hour	Pick-up/drop off spaces needed per hour (rounded up)	Average Peak Period Parking Supply
Single family home	2,500		0.77	1.93	0.02	1	2
Mid-size apartment building	80,000	120	0.35	42	0.53	1	168
Clothing retail store	2,000		3.83	7.66	0.1	1	26
Post Office	4,500		2.71	12.2	0.15	1	149
Medical Office	50,000		0.8	40	0.5	1	200
Bank	4,500		2.63	11.84	0.15	1	38
Hotel[56]	80,000	100	0.53	53	0.66	1	130
Convenience store	2,000		73.1	146.2	1.83	2	11
High-rise apartment building[57]	160,000	420	0.34	142.8	1.79	2	840
Mid-size office building	80,000		1.56	124.8	1.56	2	160
High turnover (sit-down) restaurant	6,000		13.53	81.18	1.01	2	86
Coffee shop	2,000		64.21	128.42	1.61	2	37
Athletic Club	30,000		3.19	95.7	1.2	2	117
Library	30,000		4.17	125.1	1.56	2	105
Supermarket	30,000		7.07	212.1	2.65	3	174
High-Rise Office Building	160,000		1.56	249.6	3.12	4	320
Retail Center	50,000		6.84	342	4.28	5	250
Shopping Center	400,000		0.96	384	4.8	5	2,200
Elementary School	100,000		5.2	520	6.5	7	100
Football stadium[58]	1,500,000		46.5	69,750	871.88	872	1,600
Park-and-ride[59]	250,000 (mainly parking)		6.4	1,600	20	20	

29 Average per 1,000 Sq. Ft. GFA, AM Peak
30 The ITE manual provides trip generation rates per apartment unit
31 The ITE manual does not provide trip generation for these specific land uses
32 The ITE manual does not provide trip generation for these specific land uses

Assuming a constant rate of arrival of trips and parking demand, many land uses only require 1 to 3 pick-up/drop-off spaces in the morning peak period. A large shopping center, prevalent in suburban jurisdictions, sees around 380 arrivals in the peak period, which could be accommodated by only five curbside spaces. In comparison, shopping centers often provide 2,000 or more parking spaces. Office buildings with around 250 arrivals in the peak period, which typically require approximately 300 parking spaces, could be accommodated by around 4 pick-up and drop-off spaces.

As the ITE manual only provides trip generation rates for certain land uses, a supplementary analysis looked at two specific parking facilities in Seattle and estimated the necessary loading zone space to accommodate the same level of throughput. The parking facilities are the Seattle Municipal Tower parking structure and the Eastgate Park and Ride facility. Assuming a constant rate of arrival for peak trips, the loading zone requirement was calculated for both structures. Initial estimates predict a requirement of around 6 loading zone spaces for the Seattle Municipal Tower and around 20 loading zone spaces for the Eastgate Park and Ride facility. The Eastgate Park and Ride facility analysis used a slightly different methodology than the land use typologies mentioned above. As the ITE trip generation manual does not have specific estimates for trip generation at park and ride facilities, the project team used the total number of parking spaces as a proxy for demand. The estimated 20 loading spaces are the requirement for accommodating all the equivalent 1,600 trips that terminate at the parking facility within one hour. Again, this analysis assumes that all trips arrive at a constant rate during the peak hour.

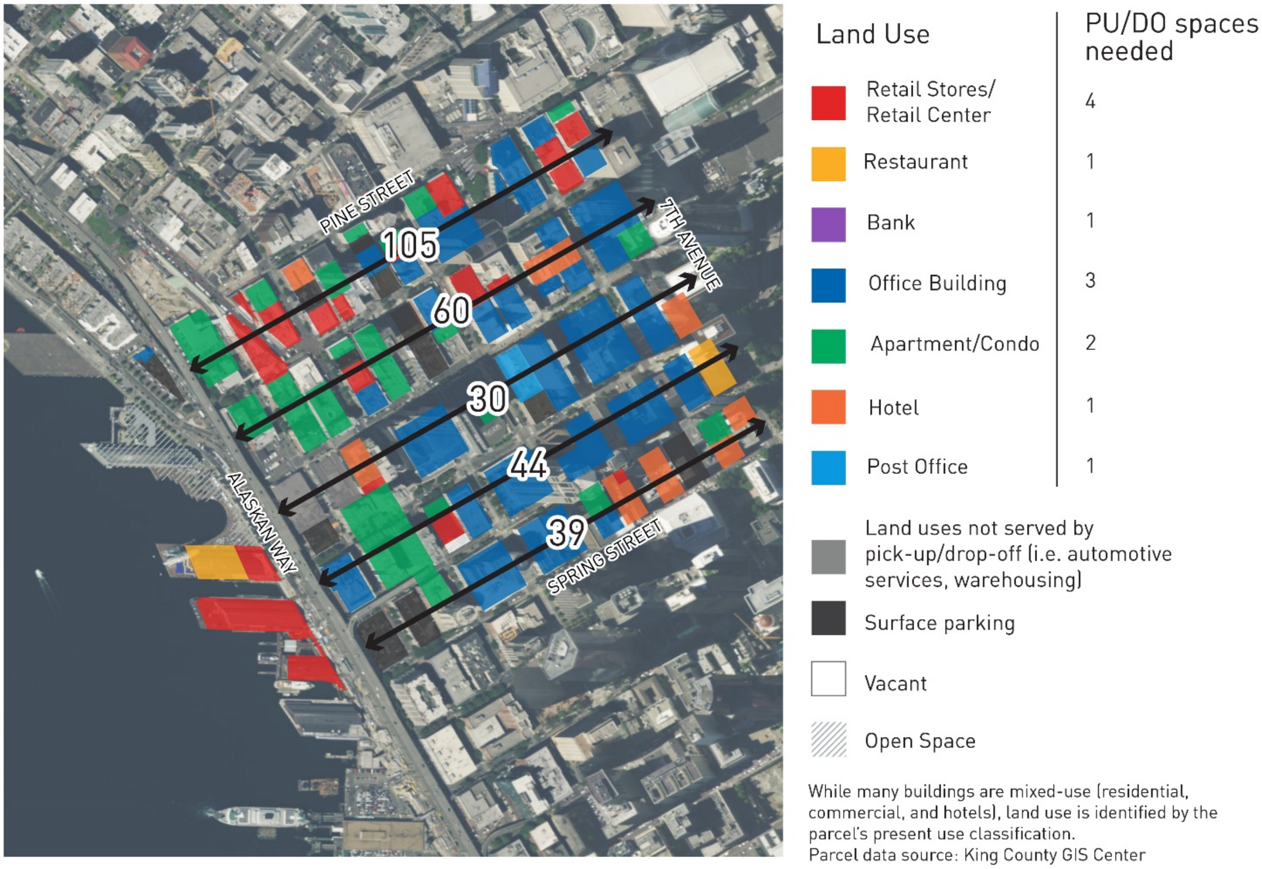
5.4 Results by Geography

The results shown in Table 5.1 were applied to three geographies to understand how curb space could be allocated in downtown areas, urban neighborhoods, and suburbs. This exercise uses the primary use of the parcel[33] to determine the pick-up and drop-off spaces needed. For example, if a high-rise apartment building in downtown Seattle also has restaurants and retail on the first floor, the pick-up and drop-off rate is calculated using the trip generation rate for the apartment building, which is its primary designation.

The numbers on the map represent the estimated curb space requirements for all the land uses on each street if trips were accommodated by rideshare, ridesplit, or taxis. These results provide a basic understanding of curb space requirements where there is a mix of residential, commercial, and office uses.

33 Parcel use defined by the King County GIS parcel dataset,

Figure 5.3: Total pick-up and drop-off spaces needed, Downtown Seattle Sub-Area[34]



Downtown Seattle is predominantly a mix of mid to high-rise office and apartment buildings with first floor commercial uses. The sub-area identified in Figure 5.2 has an on-street parking supply of 15 spaces, as well as parking garages and underground parking. The blocks between Pike and Pine Streets have the highest portion of retail uses in the area in addition to a number of offices and condominium buildings, could be served by around 100 pick-up and drop-off spaces total. The blocks further south on Spring Street would require less dedicated pick-up spaces as they are mainly office buildings and hotels and include less retail space. Should surface parking lots be developed into more productive uses, the number of required shared mobility loading spaces would need to be re-analyzed and correlate to the volume of subsequent increased trips to the area.

Based on the average peak period parking demand ratio associated with each of the land uses in Figure 5.2, the total parking supply required in this area is approximately 42,000 spaces, assuming no shared parking. However, the number of pick-up and drop-off spaces required for this area is around 330.

34 Sub-area boundaries are from Pine to Spring and Alaskan Way to 7th Avenue.

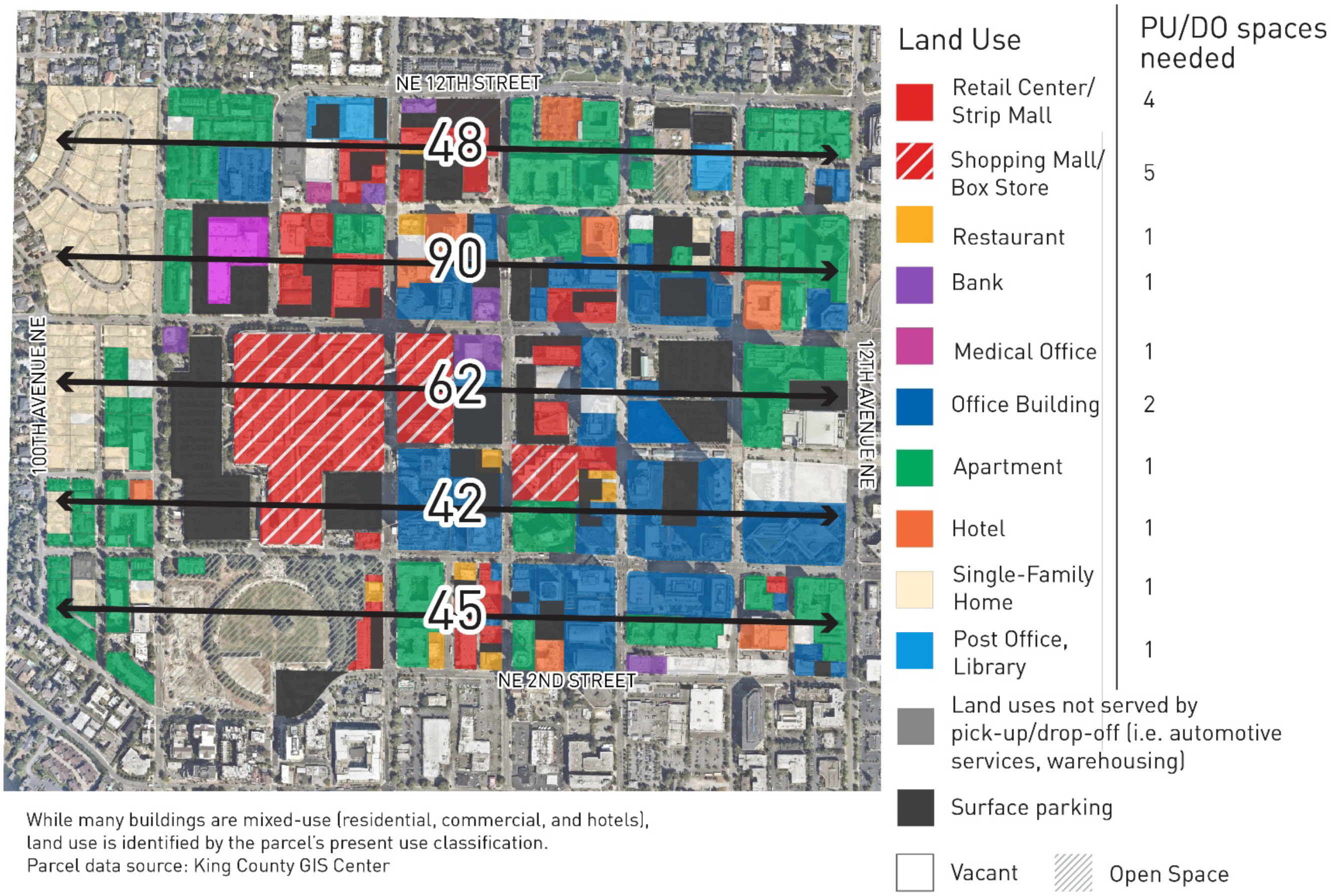
Figure 5.4: Total pick-up and drop-off spaces needed, Ballard Neighborhood Sub-Area[35]

This sub-area of Ballard is a main commercial area and is surrounded by industrial uses adjacent to Salmon Bay and residential areas to the north and east. At this scale, examining the necessary curb space for shared pick-up and drop-off space on each block provides an understanding of the potential to eliminate a portion of the on- and off-street parking supply. As this is an area where people may walk to multiple destinations once they arrive to the neighborhood, the number of pick-up and drop-off spaces needed may be even further reduced. Shared mobility options do not adequately serve industrial and warehousing land uses and therefore were not included in the analysis.

Based on the average peak period parking demand ratio associated with each of the land uses in Figure 5.3, the total parking supply required in this area is approximately 4,800 spaces, assuming no shared parking. However, the number of pick-up and drop-off spaces required for this area is around 55.

35 Sub-area is bound by NW Market Street to the north, 20th Avenue NW to the east, and Shilshole Avenue to the southwest in the Ballard neighborhood of Seattle.

Figure 5.5 Total pick-up and drop-off spaces needed, Bellevue Sub-Area[36]



While many buildings are mixed-use (residential, commercial, and hotels), land use is identified by the parcel's present use classification.
Parcel data source: King County GIS Center

This area of Bellevue is composed of a mix of land uses including shopping malls, mid-size office buildings, single-family homes, and apartments. A large amount of surface parking exists, especially near the shopping mall and retail centers or strip malls. Bellevue Square Mall alone has a parking lot with more than 1,000 spaces. Based on average parking supply ratios for each land use, the parking supply in this area is approximately 28,000 spaces while the required pick-up/ drop-off spaces is around 300.

The pick-up/ drop-off space estimation for Bellevue was determined using the same methodology as the other geographies. However, since TNC use is less prevalent in suburban jurisdictions and there is higher auto-dependence, the estimation of spaces needed could be made more conservative in further analyses. This may be achieved by decreasing the assumed number of arrivals by shared modes per hour.

5.5 Lessons Learned

- While this model does not suggest rideshare or taxi pick-up and drop-off spaces will replace the parking supply, it does assume that trips generated by each land use are fulfilled by rideshare or ridesplit services that do not require vehicle storage on-site. This methodology estimates the size of pick-up and drop-off space needed. The model could be made more conservative by adjusting the number of trips assumed to be arriving by taxi, rideshare or ridesplit vehicles. This could be accomplished by comparing available data from TNC trips on origin and destinations to current mode

36 Sub-area is bound by NE 12th Street to the north, 12th Avenue NE to the east, NE 2nd Street to the South, and 200th Avenue NE to the west in the city of Bellevue.

split in the study area. Another approach could include identifying land-use types most often serviced by TNCs and planning for pick-up and drop-off spaces on those blocks.

- Weaknesses of the model include that only one land use is assumed for each building and an average square footage is used. If this model were to be used in an area to determine curb space requirements, specific building size and mixed-uses would need to be incorporated, as well as space used for bus stops or other curb space uses.
- An important assumption of this model is that trips are assumed to arrive at a constant rate throughout the hour, however this is not likely for every land use. For example, an elementary school may experience a sudden peak in trip arrivals between 8:00 and 8:30 am, which could result in queuing and potential traffic congestion. To further improve this model for a specific land use or geography, a queuing model would account for more uneven arrival rates.[37]
- The assumption of how long it takes for an arrival and departure to occur might be reviewed and given a more conservative margin, or perhaps a range, for suburban environments to show sensitivity for the different land uses and density.
- As curb space is limited to the width of a block, congestion issues may occur along high demand blocks or corridors, creating latent demand in which the rider travels to a different area when they are not able to conveniently access the block. Latent demand is experienced today along retail/commercial corridors when incoming drivers are not able to locate a parking space, ultimately leading them to leave the area altogether. Although latent demand is difficult—if not impossible—to calculate, it can be prevented or alleviated by pursuing infrastructure investments or policies that improve the circulation and traffic flow of curb space.
- Another possible outcome of shifting travel patterns toward shared mobility and away from individual car storage is capturing the latent demand of additional patrons who are not currently able to access these services. Latent demand could come from patrons who are physically constrained, have limited access to transportation services, or not able to locate a parking space during peak demand periods. It is possible that the demand for these curb spaces could be even greater than the numbers estimated above due to the latent demand associated with these users.

5.6 Policy Implications

- There is great potential to reduce the amount of right-of-way space required per trip if people do not drive their own vehicle. The reduction in vehicle storage provides an opportunity to utilize urban spaces for more productive uses that serve more people.
- Results of this analysis can be utilized for decision-making related to optimizing the public right-of-way and integrating shared mobility into the transportation system. For example, the reallocation of curb space to accommodate pick-up and drop-off needs balanced with bus zones.
- The model identifies the potential for drop-off spaces for various land-use types and the need to investigate this in more detail on a neighborhood level or as part of future sub-area plans, such as One Center City.
- Careful planning and mitigation of potential conflicts between pick-up and drop-off space and transit and bike infrastructure is critical.
- Replacing parking spaces with pick-up/drop-off spaces will have major implications on zoning, parking requirements, park-and-ride facilities, and other uses. SDOT should consider developing a network of TNC and taxi/for-hire pick up/drop off "stations".

37 Methodology to set up a spreadsheet using queuing theory: "Queuing Theory Cookbook." Samuel L. Baker, 2006. http://web.ist.utl.pt/mcasquilho/acad/or/queue/SBakerQCookbook.pdf

- This analysis provides the first steps to consider the transformation of current park-and-rides or surface parking lots to shared mobility hubs. Placing many mobility options in one place with further integration between modes is the first steps toward a true MaaS system. The Mobility as a Service (MaaS) model is particularly conducive to shared mobility services and reducing the need for car storage facilities in urban areas, as it eliminates the need for personal vehicle ownership and encourages the use of transit, carsharing, and ridesharing services instead. SDOT and Metro should consider adopting policies which encourage the adoption of the MaaS model to reduce the need for excess parking and decrease congestion associated with SOVs.
- By definition, these loading zones take much less physical space than parking for the same trips. However, the increase in pick-up/drop-off activity puts increasing pressure on curb space which already accommodates many other uses, such as bus stops, dedicated space for emergency vehicles, loading zones, and public plazas. Therefore, at places with high peak activity levels, specific measures for off-street loading and unloading become necessary to prevent degradation of roadway throughput.
- As parking supply and demand data for each of these sub-areas was not provided, a comparison of space dedicated for parking versus non-parking uses for each land use is based on average peak period parking demand ratios provided by ITE. To complete an adequate parking analysis for individual sites or areas, a more in-depth evaluation of specific parking utilization patterns, land use distribution, and parking demand ratios, would need to be completed. Replacing parking facilities with pick-up/ drop-off spaces would be a next step for this analysis and should be performed on a site-specific basis.

Chapter 6: Transit Analysis

6.1 Model Logic

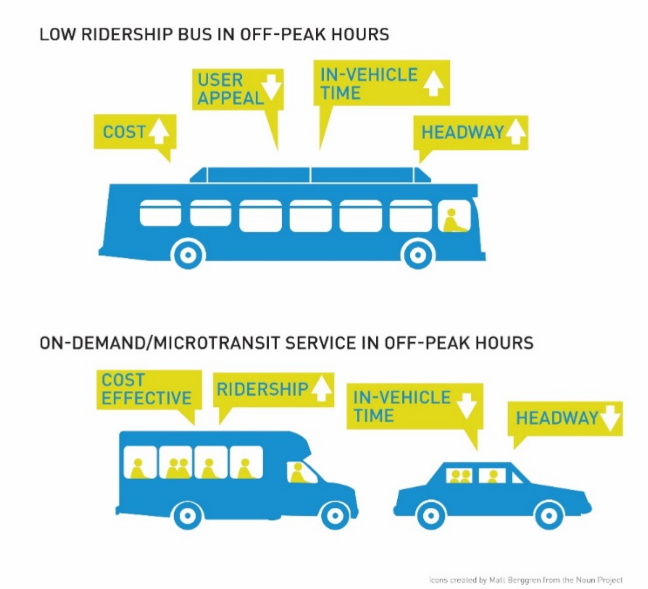
The transit analysis model identifies potential King County Metro bus trips that may be better served, at a comparable cost, using shared mobility services. The model's intent is not to prescribe the replacement of bus service with shared mobility or recommend a specific solution. Rather, it identifies low-ridership bus runs, or trips, that may be better served by a dynamically-routed (rideshare or microtransit) transportation solution in comparison to Metro's primary option of fixed route service utilizing a 40-foot or 60-foot bus.

The analysis evaluates ridership data from all Metro local, non-express bus runs. The data is broken down by each bus run, or trip, and the model identifies specific low-productivity runs where there is a cost-neutral or a cost savings if Metro paid for a rideshare trip for each current customer. The rationale for this model is that dynamically-routed transit would be preferred from a customer point of view and be a cost-neutral or more cost-effective transit solution for Metro. The output of this analysis includes which runs of specific routes at what times may be good candidates for a dynamically routed service.

6.2 Methodology and Assumptions

The analysis utilizes King County Metro data[38] and identifies bus runs with headways over 15 minutes with less than six boardings per mile which operate during low congestion time periods. Headways over 15 minutes were considered 'low productivity' runs, defined as a circumstance where Metro provides these services based on service coverage mandates. All transit agencies include these runs in their system as they are an important part of the network to ensure system connections remain intact. However, these "low productivity" runs could potentially be supplemented or replaced by point-to-point mobility options or microtransit. This analysis assumes that the customer's fare would remain equal to a transit fare if the trip was alternatively provided by rideshare, ridesplit, or microtransit.

Figure 6.1: Qualities of off-peak buses versus on-demand/microtransit



38 Service file provided by Metro reports on Spring 2016 data. The table contains data on all service and deadhead trips Metro operates and subcontracts to others. The data is pulled from scheduled service data.

Step 1: Identify costs for providing dynamically-routed transportation services

The first step in the process was to identify a formula that provides accurate costs of offering dynamically-routed transportation services. Working under the advisement of Metro, the analysis utilized Uber rideshare (1 passenger) costs for this formula.[39] These costs were chosen because Uber's rideshare service was available throughout Metro's service area and it was determined the best basis to identify an opportunity cost for providing service. While other forms of microtransit and ridesplit services may have less-expensive price points, they were limited in availability at the time of this analysis.

The calculation is based on Uber's costs from Summer, 2016 and includes the following inputs:

Table 6.1: TNC Costs

TNC costs	
Base fare ($/trip)	3.30
Mileage fee ($/mile)	1.37
Time fee ($/hour)	13.20
Assumed travel speed	15 MPH

Trip costs were calculated from these inputs with the addition of data for average trip length, which is determined in Step 5 of the analysis.

Step 2: Acquire data from Metro to identify "low productivity" runs

Data sources from Metro were acquired with the intent of identifying bus runs that had low ridership.

Table 6.2: Metro service data

Data	Description
Trip ID	Bus run or unique trip of a Metro bus route
Route	Bus Route
Direction of trip	Direction the bus is travelling (inbound/outbound)
Period	Time period when the observed trip operates
Observations	Amount of data observations for the data set
Bus distance	Distance the bus travels on the particular trip
Average Trip Length/Trip	Average trip length per customer derived from Orca Card data
Average boarding	Average boardings per trip.

Step 3: Eliminate express routes and low observation data

The next step was to eliminate express routes and bus runs with low data observations. Express routes were eliminated since, by design, the express routes carry passengers for long distances and have different measures for productivity; therefore, the cost per passenger mile calculation is not comparable.

39 Uber prices for this analyses were taken from a day in Summer, 2016. Prices shift often which is not reflected here.

Low data observations, those runs that had four or less observed data inputs, were eliminated because of the limited sample size.

Step 4: Calculate boardings per mile

To calculate average boardings per mile from the refined data set, the average number of boardings is divided by the bus trip distance:

Boardings per mile= average boardings / bus distance

Step 5: Calculate passenger miles traveled

To identify all the passenger miles served, the following calculation was used:

Passenger miles traveled= average boardings x average trip length

The result identifies the length of all passenger trips for one bus trip and combines it into one number.

Step 6: Calculate the cost to Metro for each trip

This step calculates the cost to Metro for providing each trip. Metro provided a per mile cost of $12/mile which was multiplied by the bus distance for the trip.

Cost per mile x bus distance

Step 7: Calculate Metro cost per passenger mile

To compare the cost of providing a bus trip to the cost of moving these customers on a rideshare trip, the following calculation was used to identify Metro's cost per passenger mile:

Cost per passenger mile= Metro cost of trip per passenger / Passenger miles traveled

This result can be compared with the cost of rideshare (in step 8).

Step 8: Calculate the cost of providing all passenger trips through TNCs

Step 8 analyzed the cost to provide a rideshare trip for all customers on the bus run for the distance that each customer travels. The cost of the rideshare trip is calculated using factors of (1) base fare ($3.30/trip) combined with a mileage fee ($1.37/mile) and a time fee ($13.20/hour) based on the average trip length multiplied by average vehicle speed.

Cost to Metro to provide TNC trips = Average boardings x cost of rideshare

This determines the cost of purchasing a rideshare trip for all passengers on each trip.

Step 9: Calculate bus runs that would be cost-neutral or cost-effective if provided by TNC

The final step of this analysis is to calculate the difference between Metro's cost per passenger and cost of providing all passenger trips through TNCs. This will determine if the trip cost would be equal to or lower, should the trip be provided through rideshare trips.

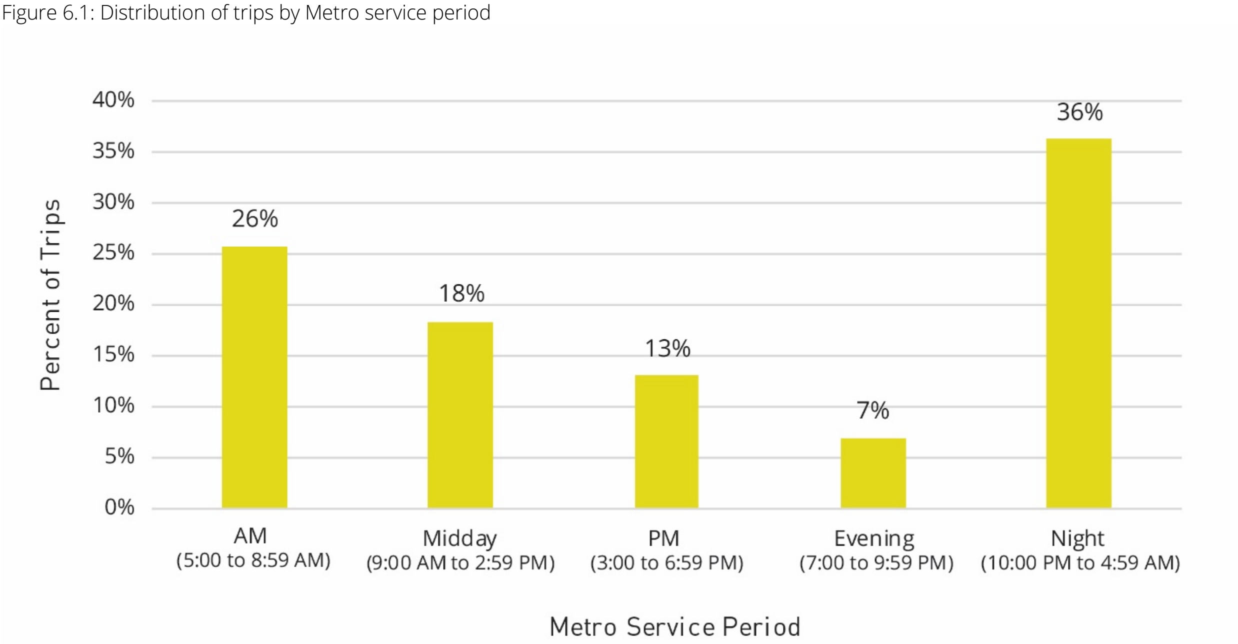
= Metro's cost of trip – cost to provide trips through TNC

Positive results identify savings to Metro by trip if Metro stopped running the bus trip and bought every customer a TNC trip.

6.3 Results

An analysis of the productivity of Metro's non-express bus service (around 8,600 trips) shows that 5% of runs and 4% of service miles would be cheaper to the agency if provided by TNC (Figure 6.1). As Figure 6.2 shows, around one-quarter of these trips occur between 5:00 am to 9:00 am and one-third occur from 10:00 pm to 5:00 am. Based on the average trip length, the costs to King County Metro for these services are approximately $8.65/rider. This analysis is a starting point for potential partnerships with shared mobility services to continue providing consistent service during low-ridership periods at a lower cost. Results of this analysis can be utilized for decision-making regarding future planning efforts related to integrating shared mobility into the transportation system.

Figure 6.1: Distribution of trips by Metro service period



The results of this analysis include all routes and trips sorted by cost differential of providing the trips through rideshare compared to fixed bus route service.

Figure 6.2: Cost differential by number of runs for Metro (non-express) bus trips

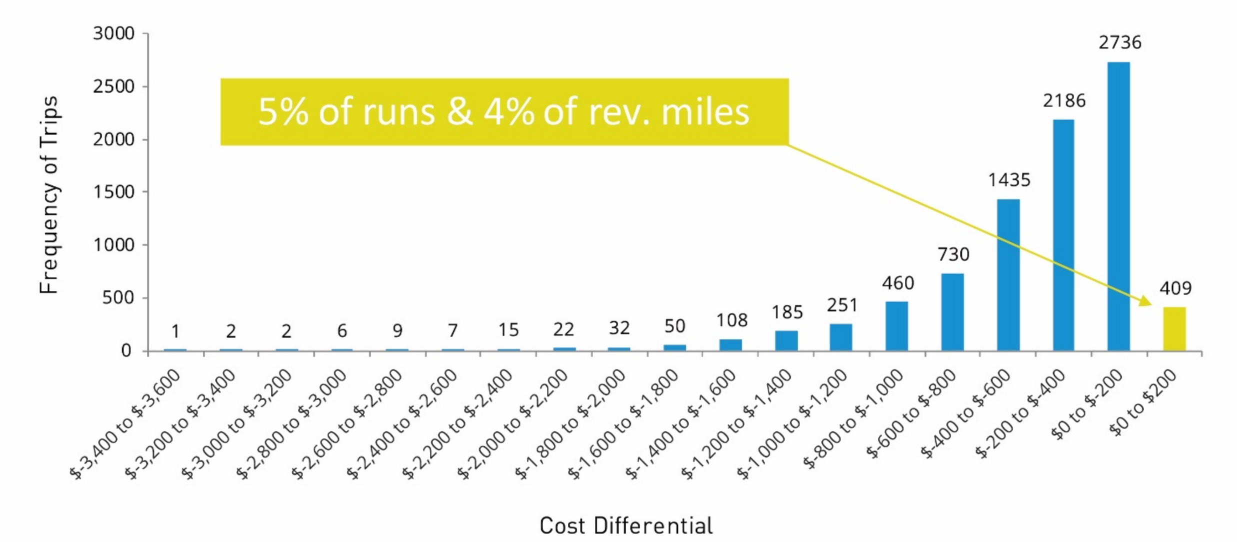


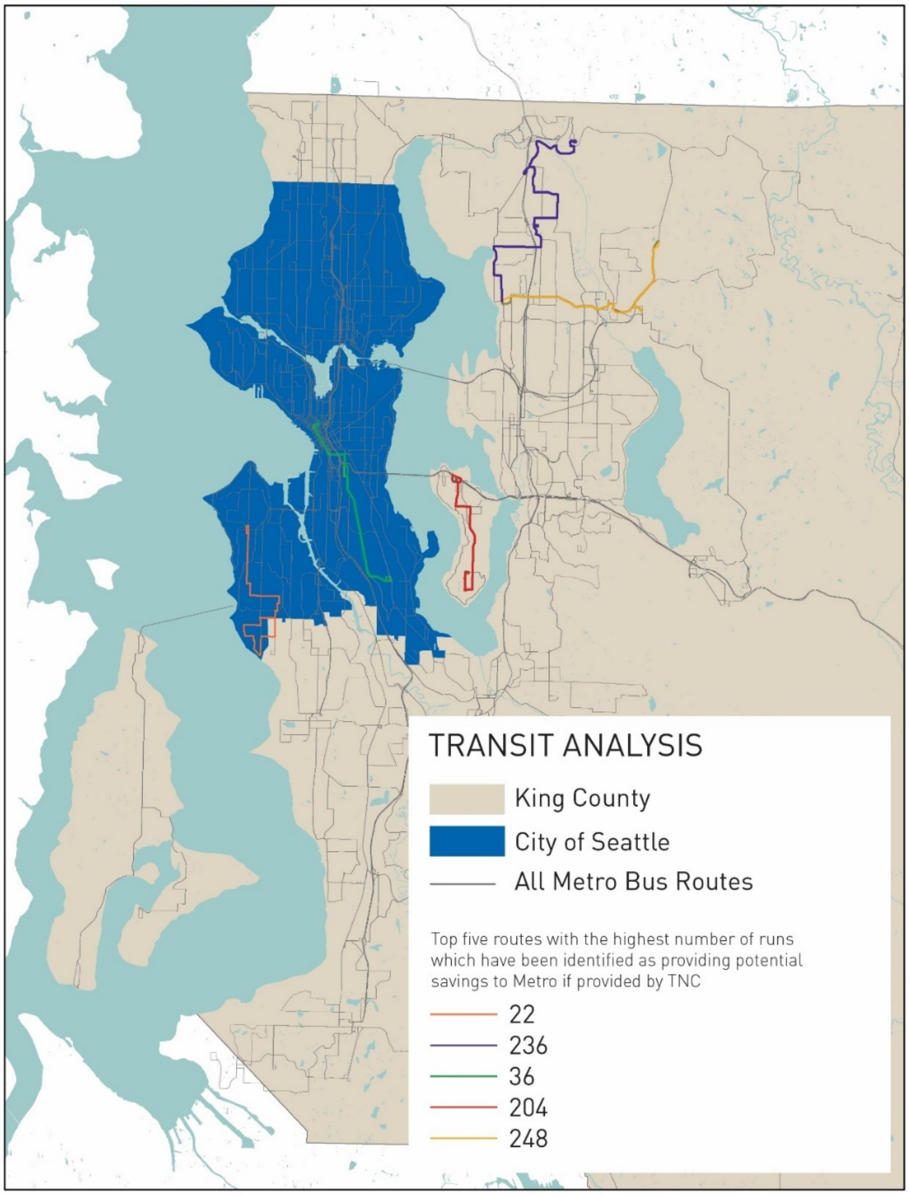
Table 6.3 and Figure 6.2 identify the top five routes with the highest number of runs which have been identified as providing potential savings to Metro.

Table 6.3: Number of runs for the top five potential cost saving routes[40]

Route	Number of Runs
Route 236 - Woodinville P&R to Kirkland TC	30
Route 204 - South Mercer Island to Mercer Island P&R	23
Route 36 - Othello Station to Beacon Hill to Downtown Seattle	20
Route 248 - Avondale to Redmond TC to Kirkland TC	18
Route 22 - Arbor Heights to Westwood Village to Alaska Junction	17

40 King County Metro Service Data, 2016.

Figure 6.2: Top five routes with highest number of runs which have been identified as providing potential cost savings to Metro if provided by TNC



Route 236 Woodinville Park and Ride to Kirkland Transit Center has the highest total number of runs at 30 (including both inbound and outbound trips). Each run for each route was observed at various times throughout the day. For example, consecutive runs of route 236 were observed at the following times: 5:22 am, 5:42 am, 6:13 am, 6:20 am, 7:13 am, 7:16 am, 8:14 am, 8:17 am, 9:13 am, 9:16 am, 9:42 am, 10:13 am, 10:16 am, 10:47 am, 11:12 am, 11:18 am, 12:13 pm, 12:18 pm, 1:12 pm, 1:18 pm, 1:42 pm, 3:28 pm, 3:58 pm, 4:57 pm, 5:54 pm, 6:02 pm, 6:25 pm, 7:00 pm, 7:02 pm, 7:33 pm.

Analyzing the number of runs, the time of day for each run, and cost differential for routes will assist in identifying the least cost-effective routes and/or periods of bus service.

6.4 Lessons Learned

The following are lessons learned and limitations of the analysis:

- This analysis does not identify a front-haul, back-haul relationship for routes that operate in the peak. Some runs with low ridership are in service to get the bus back to the starting point for peak-period peak-direction trips that are very productive.
- The major limitation is that many of the low-productivity routes or segments may be in place for coverage reasons or to build new market growth. It may not be advantageous to cut the routes as they may reduce the reach of the transit network.
- Induced demand was not included in the calculations. It is assumed there would be more demand when replacing fixed route service with more agile service, especially for customers that currently must walk to the bus stop. While there may be limited information on the effect of induced demand, further investigation will help to further evaluate the trade-off in which TNCs and microtransit may provide more cost-effective mobility over low utilization bus lines.

6.5 Policy Implications

Policy implications of this analysis include the following:

- The model's intent is not to prescribe the replacement of bus service with shared mobility or recommend a specific solution. Rather, it identifies low-ridership bus runs, or trips, that may be better served by a dynamically-routed (rideshare or microtransit) transportation solution other than a 40-foot or 60-foot bus.
- This analysis is intended to be a starting point for discussion on where fixed-route bus service could be replaced by more agile, lower capacity, microtransit or shared mobility. It is not necessarily intended to recommend routes that should be converted to a partnership with rideshare services. Further analysis on the corridor is required as well as outreach to ensure there are no unintended consequences.
- The analysis could also be utilized to combat opinions that transit should be replaced by rideshare. 95% of Metro's service would be more expensive to operate if it was outsourced to or replaced by rideshare.
- Additional investigation is recommended with Metro Service Planning prior to considering any adjustments in service. This is because many of the trips identified in the analysis may include either (1) newer trips that are under a trial period to grow ridership; these trips are commonly the first or the last trip; and/or (2) trips that are run for coverage reasons according to Metro's service standards. Next steps would include comparing these routes to Metro's Service Guidelines Analysis.
- Ways to seamlessly integrate fare payment for transit and shared mobility for this concept is necessary and would be a first step towards an important aspect of MaaS.
- Any change in service could affect Title VI implications, especially if vehicles are not ADA compliant. Coordination with the FTA is paramount prior to establishing any replacement of fixed-route operations.

Chapter 7: Shared Mobility Supply (SUMC)

7.1 Model Logic

The **Shared Mobility Benefits Calculator**, created by the Shared Use Mobility Center (SUMC), explores the benefits of transit, car share, bike share, and rideshare. The tool allows the user to select a target vehicle reduction and a mix of shared modes. The results identify decreases in VMT, GHG emissions, and savings of personal vehicle transportation costs. Results of this analysis can be utilized for decision-making regarding future planning efforts related to making shared mobility equitable to all, integrating shared mobility into the local and regional transportation system and optimizing the right-of-way.

The Shared Mobility Benefits Calculator was run through SUMC's web toolkit, available at http://calculator.sharedusemobilitycenter.org/#/ utilizing the results of the Economic Model for key inputs on vehicle reduction.

7.2 Methodology and Assumptions

The model estimates vehicle ownership based on data provided by the U.S. Census 2014 American Community Survey (ACS). Data variables from the 2014 ACS include the journey to work patterns and total workers, which is used to calculate density. Then, the model utilizes statistical techniques to produce metrics based on the census and other data, including bike share and car share locations and usage information. Tests by the SUMC proved this model to be accurate based on a set of variable coefficient values. The table below shows the coefficient values used to model increases or decreases to car ownership:

Table 7.2- Variable Coefficient Values used in SUMC Shared Mobility Benefits Calculator

Variable	Effect on Vehicle Ownership
Car share	11.27 fewer cars per car share vehicle
Carpool/Rideshare	0.2 fewer cars per carpool user
Vanpool	0.26 fewer cars per vanpoool user
Bikesharing	0.16 fewer cars per bike shared bike
Transit commuters	0.22 fewer cars per new transit commuter
Working Population	1.31 cars added per person

This model contends that public transit (including vanpool and transit commuters) and car share are the two most effective variables in reducing vehicle ownership. The model's car share coefficient depicts round-trip car share vehicles rather than one-way car share vehicles as one-way car share is still relatively new and not as geographically widespread.

This exercise uses the inputs of scenario 4 of the Economic Model, a 27% reduction in total vehicles, and applies it to the calculator for the City of Seattle (the only geography in the region available on the calculator). As scenario 4 is the only scenario that includes transit, ridesource, ridesplit, and carshare, the SUMC model is utilized as an additional method to calculate how a 27% reduction of vehicles could occur with a range of transportation options. These numbers represent what the total size of such carsharing or bikesharing fleets might look like to achieve the same reduction of 27% based on existing factors. That is, the economic model defines the bounds of vehicles that would be reduced due to the systems described above, and the factors describe the equivalent size of the system that would support that reduction. The results show the count of additional units per mode needed for Seattle, such as number of car share vehicles, transit commuters, or shared bikes.

The outputs of the Shared Mobility Benefits Calculator were applied to the report's study areas. As neither King County nor other neighborhoods and cities in the region are currently available through the calculator, the results for the city of Seattle were applied to the study areas based on the difference in total vehicles available in each area as compared to Seattle. Therefore, this exercise assumes the same proportion of additional units needed in Seattle are also necessary in the other geographies to support a 27% reduction of vehicles. To more accurately calculate these numbers, additional data for each geography is necessary.

7.3 Results by Geography

The current number of units for each transportation mode in Seattle are depicted below:

Table 7.3- Existing number of current units by transportation mode in Seattle[41]

City of Seattle	Current Units
Transit commuters	71,117
Car share vehicles	1,391
Shared bikes	500
Ridesharers/carpoolers	29,571

Table 7.4 presents the total current vehicles, potential vehicle reduction, and additional units needed per mode as calculated by the SUMC model for the City of Seattle. In addition, these results were applied to the other study areas based on the ratio of total vehicles as compared to Seattle. The results show that transit commuters and rideshare/carpool must increase by the greatest number, followed by car share and bike share respectively.

In Seattle, to support a reduction of the personal vehicle fleet by around 110,000 (27% of total vehicles), an additional 36,000 transit commuters, 9,000 car share vehicles, 6,600 shared bikes, and 17,500 rideshare users or carpoolers is necessary

As this methodology does not account for number of units available and usage data, journey-to-work data, or total workers, the results appear unrealistic for some geographies. For example, adding 22,262 shared bikes in King County will be unrealistic anytime in the near future. Apart from the fact that Pronto bike share's program ended in March 2017, bike share systems in cities such as New York and Chicago only have 7,500 and 6,000 bikes, respectively.[42]

41 Shared Use Mobility Center Benefits Calculator, available at: http://calculator.sharedusemobilitycenter.org
42 Divvy and Citibike information available at: https://www.divvybikes.com/about and https://www.citibikenyc.com/system-data/operating-reports

Table 7.4: Additional units needed to reduce total vehicles by 27%

Geographic area	Current	27% Vehicle Reduction	Additional units needed per mode to reach reduction			
	Total Vehicles	Total Vehicles Reduced	Transit commuters	Car share vehicles	Shared bikes	Ridesharers/ carpoolers
Seattle	406,156	110,595	35,785	9,055	6,615	17,534
King County	1,366,859	372,192	120,429	30,473	22,262	59,008
Ballard	15,613	4,251	1,376	348	254	674
U-District	10,125	2,757	892	226	165	437
Colombia City	7,915	2,155	697	176	729	342
Downtown Seattle	29,358	7,994	2,587	655	478	1,267
Sammamish	33,927	9,238	888	225	164	435
Shoreline	37,811	10,296	990	250	183	485
Bellevue	89,942	24,491	2,355	596	435	1,154
Maple Valley	17,079	4,651	447	113	3	219
Kent	76,395	20,802	2,000	506	370	980

Figure 7.1: Additional units needed to reduce total vehicles by 27% in Seattle

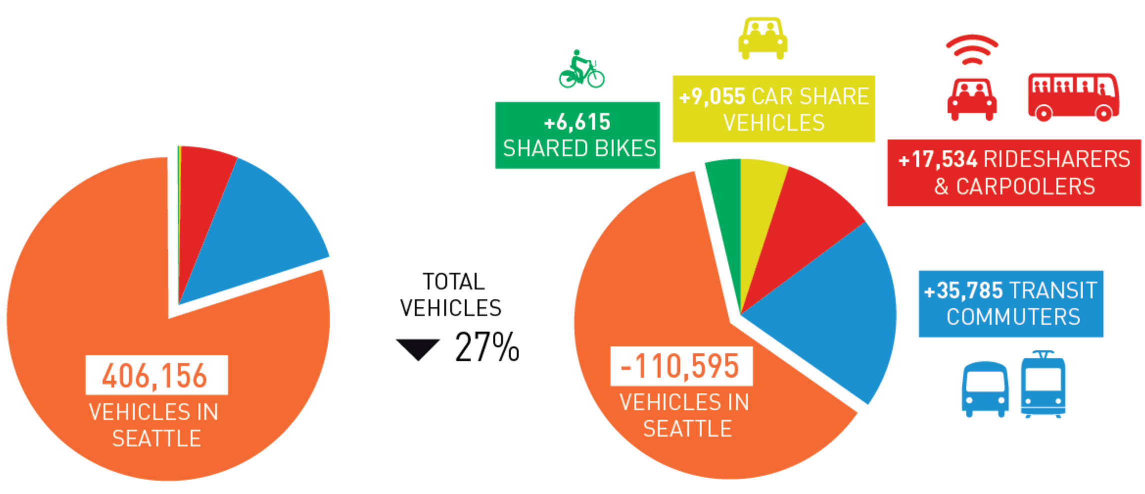


Table 7.5 exhibits the resulting benefits to air quality and transportation costs from reducing the total car in Seattle.

Table 7.5: Benefits in Seattle resulting for reduction of vehicle fleet by 27%

Reduction in miles traveled by personal vehicles	1,116,463,100
Reduction in metric tons of GHG emissions related to personal vehicle ownership	400,300
Reduction in personal vehicle transportation costs	$393,955,000

7.4 Lessons learned

- The SUMC calculator serves as a method to estimate the size of the shared mobility system that would achieve a reduction in personal vehicles. While the economic model considers a menu of shared mobility options that could replace the use of a personal vehicle, the SUMC calculator quantifies the number of transit commuters, car share vehicles, and rideshare users to support the same reduction.
- The calculator offers the option to analyze shared mobility benefits in around 30 cities, including Seattle. In this exercise, applying the Seattle results to King County, neighborhoods, and other jurisdictions only provides a precursory understanding of the potential distribution of shared mobility services in the region. Further analyses must include the number of existing units (car share vehicles, transit commuters, etc.), usage data, and journey-to-work data in each study area to provide a complete analysis.

Chapter 8: Stockholm Study

8.1 Model Logic

A study completed in Stockholm[43] found that automated transportation technology can solve mobility demands by reducing the need for personal vehicles and enable cities to become more sustainable, reduce traffic congestion, and increase road safety.

The study identified the capacity of a reduced number of vehicles to move more people with ridesharing. The study is based on the premise that self-driving vehicles, named Shared Automated Vehicles (SAVs), would provide services similar to those of existing rideshare services and for-hire taxis and replace all private SOV commuter trips.

A SAV-based transportation network could result in every personal vehicle commuter trip being accommodated while utilizing no more than approximately 10% of current vehicles and parking spaces. The study explains that while transit trips are not included in the analysis, the model can be used to identify benefits that a SAV-based transportation network could have in conjunction with an efficient public transportation and increases to cycling and walking. For example, SAVs could connect to shared mobility hubs on land previously used as parking lots to provide first-mile or last-mile transportation options. Other studies on the benefits of AVs support these findings for improving societal, economic, and environmental sustainability.[44]

8.2 Methodology and Assumptions

The study utilized scenarios to explore outcomes that a SAV-based transportation system could have for the City of Stockholm. Evaluation factors included number of vehicles needed to provide service, total vehicle miles travelled (VMT), and energy usage or vehicles parked within the city. The study found Stockholm to be a suitable city for SAV implementation based on its traffic density and traffic data availability. The model targeted an end date of 2030 to ensure relevant existing data could be used to reasonably project traffic in 2030 Stockholm. There are two main facets of this model; 1) to determine how varying input factors (wait time and travel time passengers will tolerate), impact outputs (total travel time, number of vehicles needed in fleet, and VMT) and 2) the environmental impacts of each scenario comparing fleet vehicles using internal-combustion engines or electric motors.

Step 1: Establish the road network and road network characteristics

The road network used in the model linked together a series of nodes and zones that were used in the analysis of travel time of rideshare simulations. In addition, traffic modeling software evaluated trip demand utilizing real traffic conditions in Stockholm. The traveling patterns of Stockholm County residents were used in the trip demand model to display vehicle travel from work to home during a typical weekday.

Step 2: Model SAV scenarios on road network

The next step was to model scenarios of a SAV-based system, including trips completed with or without ridesharing. To simulate SAV trip scheduling to include ridesharing, carsharing, and empty vehicle routing, an additional model was created. This model relied on the road network and assumptions of traffic congestion and driving speed.

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43 Rigole, Pierre-Jean. Study of a Shared Automated Vehicles Based Mobility Solution in Stockholm (2014). Kungliga Tekniska Högskolan, Royal Institute of Technology. Available at: http://kth.diva-portal.org/smash/get/diva2:746893/FULLTEXT01.pdf

44 Other works that have contributed to this subject include "Operations of a Shared Autonomous Fleet for the Austin, Texas Market," by Fagnant and Kockelman (2015), as well as "Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles," by Greenblatt and Saxena (2015).

Figure 8.2 – Typical time definition for trip with no ridesourcing[45]

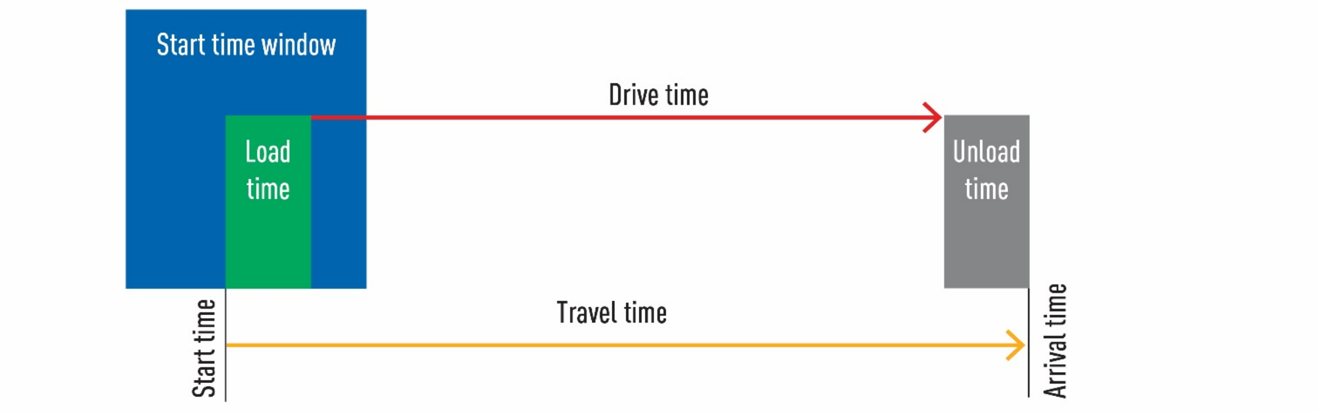
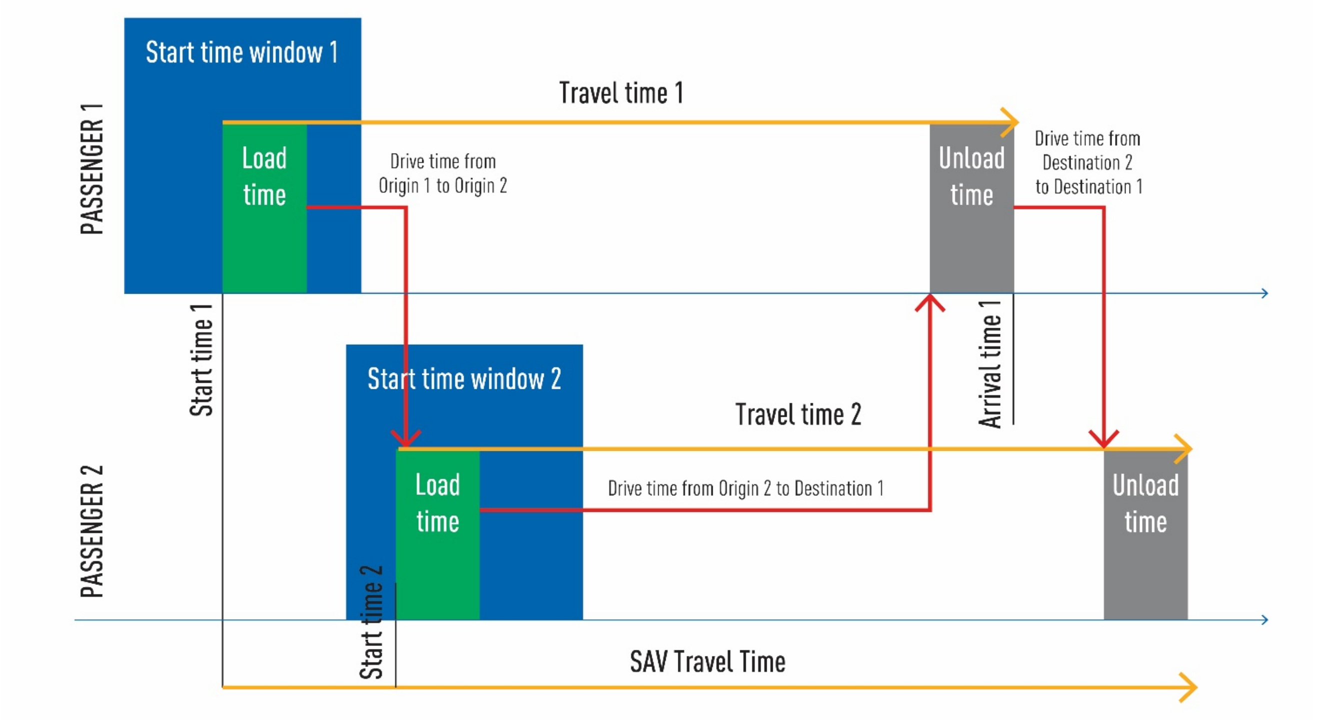


Figure 8.3- Typical time definition for trip with ridesharing[46]



45 Modified from Rigole, Pierre-Jean. *Study of a Shared Automated Vehicles Based Mobility Solution in Stockholm* (2014). Kungliga Tekniska Högskolan, Royal Institute of Technology. Available at: http://kth.diva-portal.org/smash/get/diva2:746893/FULLTEXT01.pdf
46 Modified from Rigole, Pierre-Jean. *Study of a Shared Automated Vehicles Based Mobility Solution in Stockholm* (2014). Kungliga Tekniska Högskolan, Royal Institute of Technology. Available at: http://kth.diva-portal.org/smash/get/diva2:746893/FULLTEXT01.pdf

Under step 2, rules for ridesharing were established for the ridesharing schemes:

1) Passengers are dropped-off in the same order as they were picked-up
2) The route taken is the one with the shortest drive time
3) When multiple concurrent passenger pick-ups are possible, SAVs will choose the users with the closest start time
4) The time needed for passenger exit is assumed shorter than passenger entry upon pick-up

Step 3: Add parameters to SAV scenarios

In the next step, the study based ridesourcing in a SAV-based system on the following parameters:

1) **Maximum number of passengers in vehicle -** The SAV fleet is assumed to consist of a single type of vehicle with approximately 4 seat capacity for passengers.
2) **Start time –** The earliest time for a passenger to start the trip.
3) **Start time window –** The range of time measured from the start time within which a passenger is accepting a trip.
4) **Load time** – The time given to the passenger to enter the SAV.
5) **Unload time** - The length of time given to the passenger to exit the vehicle upon arriving at the destination.
6) **Relative increase in travel** time – The increase in travel time relative to the travel time assuming no detour that a passenger is ready to accept. The increase in travel time is required to allow for picking-up additional passengers in the ridesharing scheme.
7) **Intra-zone travel time** – The amount of time taken to pick-up passengers within the same trip origin zones

Step 4: Create Optimization Algorithm

Next, an algorithm was established for determining optimized routing methods for SAV ridesourcing based on the above parameters. Three ride-sharing schemes were then used to evaluate trips based on the following trip itineraries:

1) Same origin and destination
2) Same origin and different destination
3) Different origin and same destination

The study found that SAV fleet size is dependent on the vehicles needed for trip demand in each of the above schemes as well as the expected quality of service (passenger wait time).

Step 5: Outline Performance Indicators

The model delineated key indicators for SAV fleet performance and environmental impact. They are as follows:

Table 8.1: SAV Fleet Performance Indicators

Indicator	Sub-indicator
SAV fleet	# of SAVs
Mileage	Total Average per SAV/private car Average per passenger
Travel time	Total for the fleet Average increase in travel time Average per SAV/private car Average per passenger
Start time window	Average use per passenger
Parking time	# parked SAV Total parking time Average parking timer per SAV/private car
Ride-sharing	Average of passengers per SAV

Table 8.2: Environmental Impact Indicators

Indicator	Sub-indicator
Emissions	GWP_{100} (global warming potential over 100 years)
Energy	Energy (fuel/electricity)

Step 6: Evaluate Scenario Variables
The variables below were used to evaluate each scenario:

1) **Maximum increase in travel time –** The amount of increase in time that a user would be subjected to as a result of taking a shared vehicle (multiple passenger pickup and drop off).
2) **Start time window –** The amount of time allocated from when a user accepts to start a trip to the time of actual trip start.
3) **Cost function –** This equation evaluates how SAVs are dispatched to pick up passengers. The function is set to minimize costs and does so by assessing amount of time parked between trips and the driving distance needed to travel between users.

Table 8.3: Scenario Evaluation

Scenario	1	2	3	4	5	6
Allowed maximum increase in travel time	0%	0%	30%	30%	50%	50%
Start time window (minutes)	0	0	10	10	15	15
Cost function	K1=0 K2=1	K1=1 K2=0	K1=0 K2=1	K1=1 K2=0	K1=0 K2=1	K1=1 K2=0

Scenarios 1 and 2 were modeled without ridesharing while Scenarios 3 through 6 are modeled to include ridesharing. As shown in Table 8.3, there were no increases to travel time in scenarios 1 and 2 (ridesourcing was not included, which increases the travel time as the SAV needed to pick up more people). Scenarios 3 and 4 had a 30% maximum increase of travel time and scenarios 5 and 6 included a 50% maximum increase. The cost function for each scenario measures the difference between only minimizing empty mileage (when cost function K1=1 and K2=0) and only minimizing parking time (when cost function K2=1 and K1=0).

The baseline case represents the current conditions of private single occupancy vehicles accommodating all commuter car trips. This model does not include transit, walking, or biking commuter trips. The number of person-trips is calculated by doubling the number of personal vehicles making home-to-work trips, which accounts for work-to-home trips. The model ran the scenarios using the baseline case as the controlled variable to measure the impacts of the different scenarios.

Table 8.4: Baseline Indicators

Indicators	Unit	Baseline
# person-trips (home to work + work to home)	Trips	271,868
# vehicles = private cars	Vehicles	135,934
Total mileage	Kilometers (thousands)	2,606
Average mileage per trip	Kilometers	10
Total travel time	Hours (thousands)	66
Average travel time per person	Hours	0.5
Average travel time per private car	Hours	0.5
Total parking time	Hours (thousands)	3,196
Average parking time per private car	Hours	23.5

8.3 Results

The study's main findings revealed that SAV-based systems can provide door-to-door service while using less than 10% of the current number of private cars and parking spaces. When comparing SAVs without ridesharing (scenarios 1 and 2) to SAVs with ridesharing schemes (scenarios 3, 4, 5 and 6), the latter provided the highest benefit toward reducing congestion and environmental impacts due to vehicle traffic in Stockholm. Results are presented as ratios to the baseline. Scenario 2 has the lowest reduction of vehicles, with 8.6% of total baseline vehicles accommodating all trips (meaning 91.4% of private cars reduced), while scenario 5 has the greatest reduction in vehicles as compared to the baseline at 5.4% (96.4% of cars reduced). The model demonstrates that ridesharing scenarios offer a reduction in total mileage but at the cost of quality of service for users.

Scenarios modeled to include ridesharing had both the least number of SAVs on the road as well as number of SAVs parked when compared with the baseline and non-ridesharing scenarios. For example, the medium case scenario (scenario 3) that included ridesharing provided an additional reduction of private vehicles as scenarios 1 and 2 of 2.7% and 3.2%, respectively. Utilizing the ridesharing scheme, scenario 3 reduced parking requirements by 95% while miles traveled were reduced by 11% from the baseline case.

The results of each scenario (below) are ratios compared to baseline values.

Table 8.5. Simulation results by scenario as ratios to baseline

Scenario	Unit	1	2	3	4	5	6
# Vehicles	%	8.1%	8.6%	5.4%	6.0%	4.9%	5.3%
Total Mileage	%	124.4%	171.6%	88.8%	114.6%	76.0%	96.7%
Total Parking Time	%	5.8%	5.5%	3.6%	3.8%	3.3%	3.4%
Total drive time (time on the road)	%	120.4%	157.1%	93.5%	113.5%	84.7%	100.8%
Average use of start time window relative to start time window	%	0.0%	0.0%	59.6%	24.9%	55.6%	29.4%
Average increase in travel time	%	0.0%	0.0%	13.1%	13.1%	25.1%	25.1%

The model reflects the potential of a SAV-based system to reduce the number of vehicles and parking time. The study asserts that when compared to the baseline, SAVs increase vehicle efficiency through servicing multiple users simultaneously and maximize driving time on road.

Figure 8.4: Number of SAVs per minute on road versus time. Scenarios minimizing empty miles (Left), Scenarios minimizing parking time (right).[47]

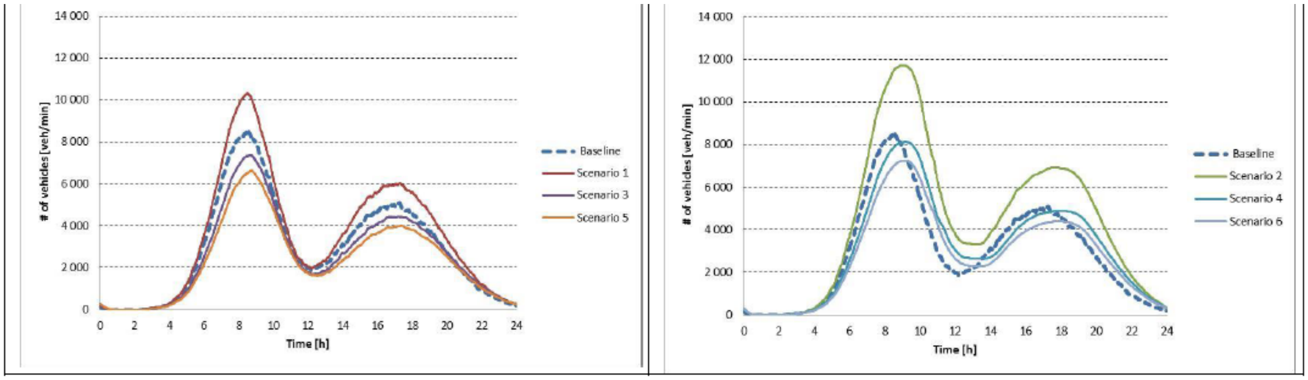
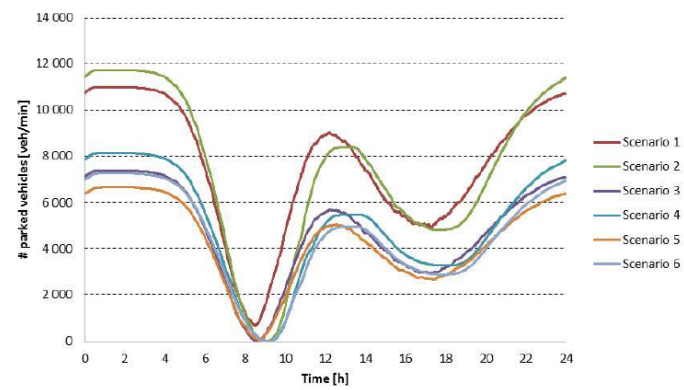


Figure 8.5: Number of parked SAVs during the day for all scenarios[48]



Based on the results of the scenarios that included ridesharing (scenarios 1-3), the study concluded that without reaching an adequate ridesharing threshold that SAVs may add to congestion and environmental impacts rather than reduce them. However, the model reveals that using SAV fleets powered with electric motors rather than internal combustion engines can negate any adverse environmental impacts.
The study addresses how SAVs will impact the triple bottom line of sustainability:

1) **Social sustainability** – The impact that SAVs would have on social sustainability over the private car includes increased accessibility to all people regardless of driving capability, such as elderly or disabled persons.
2) **Economic sustainability –** The study determined that SAVs can be an economical solution due to the cost of the vehicle being shared across many users with no additional costs for drivers/operators. Users who would rely upon a SAV-based system for transportation mobility would no longer experience the costs of owning and operating a vehicle. The study believes that these savings will be transferred into the companies of the SAV fleet owners/operators. Additionally, the economic cost of constructing parking lots will be eliminated as parking demand is reduced.

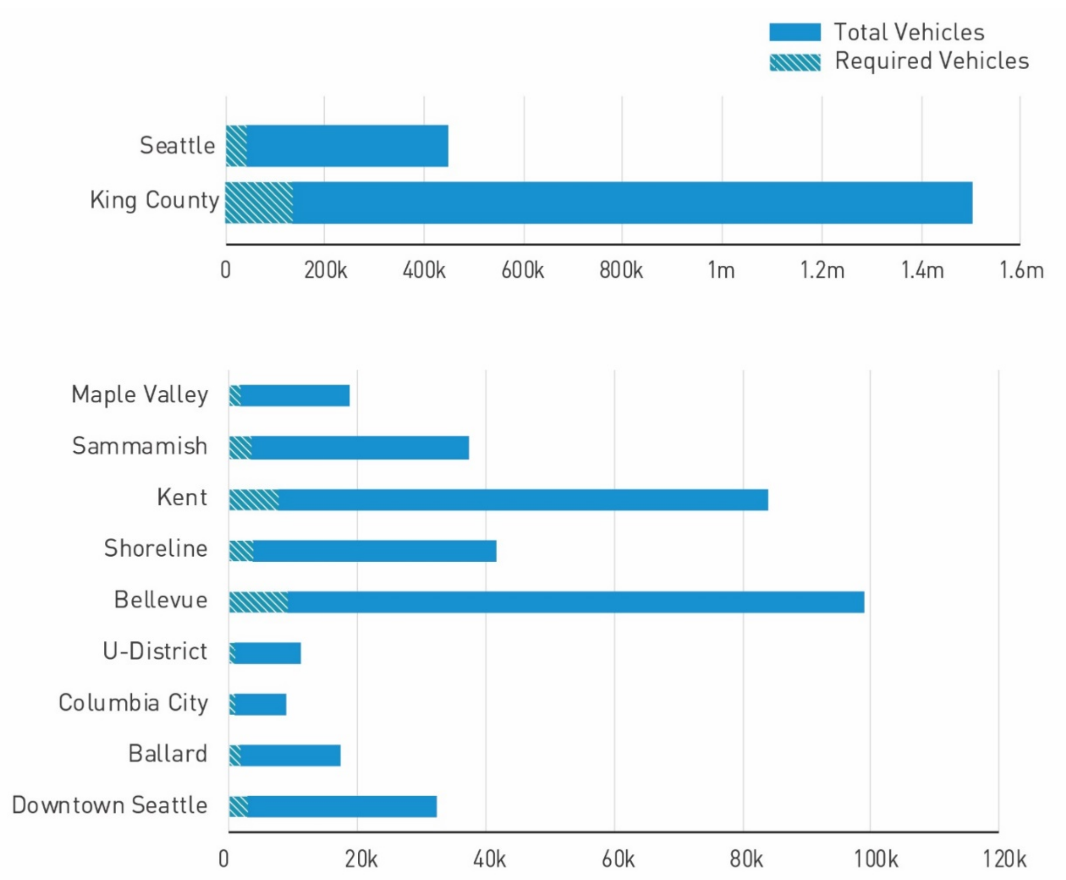
47 Rigole, Pierre-Jean. *Study of a Shared Automated Vehicles Based Mobility Solution in Stockholm* (2014). Kungliga Tekniska Högskolan, Royal Institute of Technology. Available at: http://kth.diva-portal.org/smash/get/diva2:746893/FULLTEXT01.pdf
48 Rigole, Pierre-Jean. *Study of a Shared Automated Vehicles Based Mobility Solution in Stockholm* (2014). Kungliga Tekniska Högskolan, Royal Institute of Technology. Available at: http://kth.diva-portal.org/smash/get/diva2:746893/FULLTEXT01.pdf

3) **Environmental sustainability –** The study found that a SAV-based system can help to reduce congestion and environmental impacts, though caution must be used. KTH asserts that such an easily accessible, comfortable, and lower cost door to door mobility service could possibly increase demand and consequently negate any positive environmental impacts by making other modes less appealing. However, negative impacts could be offset by advances in robotic and artificial intelligence technology leading to traffic flow increases by reducing need for spacing, stops, and accidents between vehicles. The study emphasizes that land use benefits could be made possible by reducing the parking demand in Stockholm as parking lots could be freed up for other transportation modes creating an increase in walking, cycling, and transit use.

Applications to the Seattle Region

To understand the implications of a reduced personal vehicle fleet in Seattle, a 90% reduction was applied to each geography, as shown in Table 8.6. This stated, the results should be taken with caution as the roadway networks are different from Stockholm and vary greatly between typology. Additional analysis of traffic, roadway capacity, and parking supply are necessary to provide a comparison between this study and Seattle.

Figure 8.6: Results of a 90% reduction of vehicles in Seattle neighborhoods and King County jurisdictions



8.3 Lessons learned

- This study is an early attempt to identify the potential positive benefits of a Shared Autonomous Vehicle network, with a focus on reduction in vehicles and parking spots. The exploratory nature of the modelling exercise provides initial results, but also recognizes several its own limitations, including:
    1) The study only included internal traffic that represents about 60% of all vehicle traffic in Stockholm, leaving a large portion of traffic unaccounted for.
    2) The demand is constructed on a survey using several calculation steps and assumptions. It states that they believe the total amount of traffic to be adequate but the detailed traffic flow patterns have not been verified and compared to real traffic data.
    3) The study asserts that the simulation is based on a simple model that does not include dynamic traffic simulation and utilizes simple ridesourcing algorithms. To increase accuracy on the impacts of a SAV transportation system, an advanced model would be required.
- The study proposes several areas of future study that will impact transportation and cities in the future:
    1) Social considerations – Areas surrounding safety and legal responsibility in the event of a collision should be explored further.
    2) Land Use – With a SAV system in place, excess parking lots and spaces will release land back into other uses. In addition, the current system of building infrastructure may change as space needs and travel methods of SAVs will operate under a different set of conditions than humans do.
    3) Research – Further studies on ridesharing and car sharing using more advanced models with greater dynamic conditions, SAV-based freight and goods delivery transportation systems, and comparing SAV-based systems between various cities.
- Additional limitations include that the study is based on the City of Stockholm, which has unique land use characteristics. Results will vary in US urban contexts, especially suburban contexts where trip patterns and land use characteristics are often distributed to a wider range of origin and destination patterns and longer commute lengths and times.

8.4 Policy Implications

- The study model demonstrates that SAV-based transportation can effectively and efficiently reduce a number of negative transportation, environmental, and economic impacts with no or little impact to travel time (depending on the different model scenarios). The biggest benefit for SAV systems from the model were scenarios which included ridesharing , and when coupled with an electric motor equipped fleet of SAVs, were the most effective combination to decrease traffic congestion, parking demand, and energy use and greenhouse gas emissions.
- This study contains a unique approach that can be further refined and/or built on for analysis of potential SAV or MaaS systems in the Seattle region. The methodology of this study could be combined with PSRC data that identifies high TAZ-to-TAZ travel to analyze the potential for a future MaaS strategy in the region. Finally, this data could be compared to Car2Go, Zipcar, ReachNow, Uber Pool, Lyft Line, and other shared services to identify relative potential for future SAV services in the Seattle Region.

Typology Appendix

Introduction

This section is an overview for each geography analyzed in this report. It is intended to offer an alternative lens to identify results and policy implications from the perspective of each typology. These overview summaries will provide concise geographic and demographic contexts to frame the potential impacts of shared mobility as it relates to the various geographies in Seattle and King County. Each typology is representative of different neighborhoods and suburbs in the region.

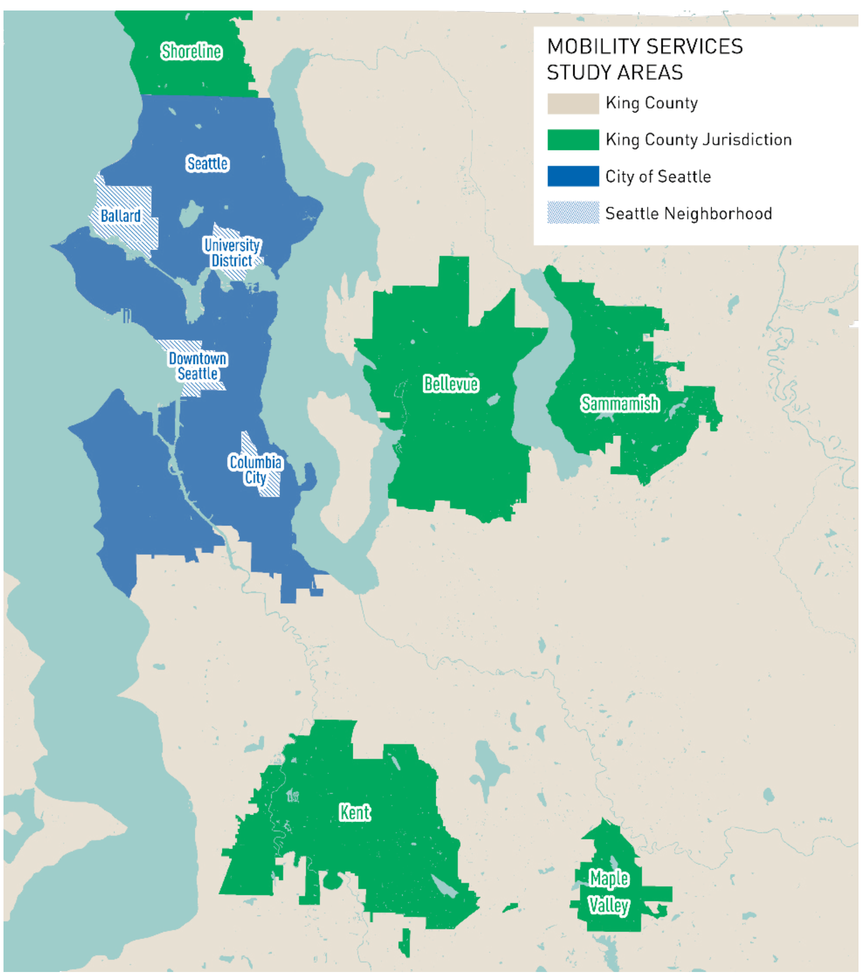
The typologies in Seattle include:

- Downtown Seattle (Center City)
- Ballard, Colombia City, and University District: representative of city neighborhoods

Typologies of King County include:

- Bellevue and Shoreline: representative of high density suburbs
- Kent: representative of regional manufacturing and shipping hubs
- Sammamish and Maple Valley: representative of exurban communities

Figure 9.1: Typology study-areas in Seattle and King County



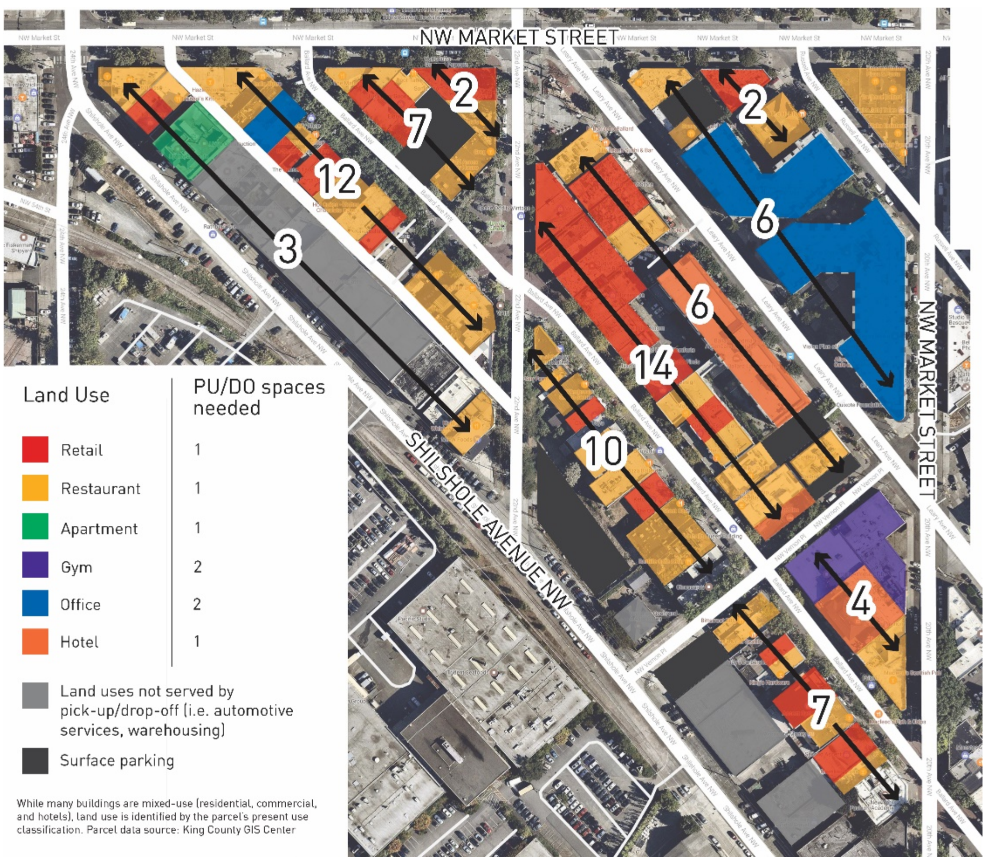
Ballard

Ballard is a relatively-dense neighborhood of approximately 2.1 square miles on the north side of Seattle and contains several regional attractions, including commercial corridors along Market Street and Ballard Avenue. Ballard is served by a variety of King County Metro bus lines and contains an entertainment district. It has a population of 22,122 and contains approximately 10,000 people per square mile**.**

The economic model (Chapter 2) demonstrates that there is a tremendous opportunity to reduce auto-ownership. Of Ballard's 15,613 personal vehicles, a reduction of approximately 2,000 to 6,000 (15% to 39%) could occur after substantial shifts to shared mobility transportation options. The potential reduction of personal vehicles through shared mobility in Ballard would have significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for Ballard as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Ballard would:

- Significantly decrease the share of SOV daily trips from 42% to 33%
- Increase transit trip mode share from 3% to 7%
- Increase total daily trips by shared mobility from 1% to 11%



This sub-area of Ballard is a main commercial area and is surrounded by industrial uses adjacent to Salmon Bay and residential areas to the north and east. At this scale, examining the necessary curb space on each block provides an understanding of the potential to eliminate some surface and on-street parking. As this is an area where people may walk to multiple destinations once they arrive to the neighborhood, the number of pick-up and drop-off spaces needed may be even further reduced. Shared mobility options do not appropriately serve Industrial, warehousing, and automobile land uses and therefore were not included in the analysis.

Based on average parking supply ratios for each land use, the parking supply in this area is approximately 4,800 spaces while the required pick-up and drop-off spaces is around 55. Ballard's small area and relatively high density would be greatly served by all modes of shared mobility and will experience the benefits of these services including reductions to congestion, parking requirements, curb

Policy Implications

As a dense urban neighborhood with a large commercial district, there are many traffic generators in Ballard, and, therefore, many potential implications for optimization and reutilization of the public ROW. Primary to these implications is the potential for overall decline in the demand for car storage (including reductions in car ownership and in visitors arriving by SOVs to the neighborhood).

As a result, this neighborhood is a key candidate to identify new alternatives for parking facilities, especially those at surface level. First, a fresh look at land-use planning should occur to identify lower parking requirements and minimize surface parking lots. Second, identification of infill development to transform these pockets of existing surface parking lots to more active uses should be studied. Third, potential for elimination of on-street parking spaces should be monitored, especially in consideration for potential to implement other uses as transit lanes, on-street bike facilities, parklets for adjacent businesses, and enhanced pedestrian facilities. These actions will require further analysis and can be implemented as part of neighborhood and sub-regional planning activities.

The next policy implication relates to safety. As with other entertainment districts, there is an opportunity to encourage shared mobility options when people become impaired due to alcohol consumption. Additional pilots, as previously performed around large events[49] and at times when drunk-driving activity most often occurs could be expanded on a regular basis.

Finally, as potential shifts to shared mobility occur, there is a once-in-a-generation opportunity to identify incentives to encourage higher-occupancy forms of shared mobility, including transit, bikeshare, and microtransit to increased optimization of the constrained roadways serving this neighborhood.

University District

University District (U-District) is located in Northeastern Seattle bounded on the south by the Lake Washington canal. U-District has a population of approximately 31,434 people and a land area of just under 2.5 square miles giving it a population density of 13,543 people per square mile. As implied by its name, the neighborhood is home to the University of Washington campus and, as such, has a large student population. Transit connections can be made using Sound Transit's Link light rail system at University Station or one of numerous King County Metro bus lines.

As the economic model (Chapter 2) demonstrates, there is considerable opportunity to reduce auto-ownership in U-District. In U-District there are 10,125 personal vehicles. The U-District neighborhood would see personal vehicles reduced by 2,000 to 4,500 (17% to 45%) vehicles having significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for U-District as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 U-District would:

- Significantly decrease the share of SOV daily trips from 37% to 26%%
- Increase transit trip mode share from 9% to 16%

49 SDOT Safe Ride available at: http://sdotblog.seattle.gov/2016/06/21/get-a-discounted-safe-ride-this-pride-weekend

- Increase total daily trips by shared mobility from 1% to 12%

U-District's higher density and student population would be greatly served by all modes of shared mobility and will experience the benefits of these services including reductions to congestion, parking requirements, curb space optimization, car-free lifestyle, and others.

Policy Implications

The U-District has many of the same characteristic and opportunities as Ballard. In addition to the policy implications identified in the Ballard section of this report, including alternatives to parking facilities, impaired user safety, and incentives for more HOV shared mobility usage, there are additional items to consider.

First, the University of Washington Station opened just over one year ago. This station leads to the center of the nieghborhood should be utilized as a local hub, connection to Center City, SEATAC, and other traffic generators along the line. There is an opportunity to create a shared mobility hub at this station to provide and encourage easy first and last mile connections.

Next, the University of Washington hosts major events on a regular basis. These events range from arts and culture to large sporting events. Attendance for these events also ranges from the 100's to over 70,000 for football games at Husky Stadium. Special events strategies to nudge attendees to higher capacity modes can ease congestion on local streets and reduce impacts of these major events.

Finally, there is a large student population that lives and commutes to U-District on a daily basis. The City and Metro should work with the University of Washington on MaaS solutions to encourage car-free travel to and from campus. There is the potential to create intra-campus MaaS networks, as well.

Columbia City

Columbia City is located in Southeastern Seattle and has a population of 12,531 people. The neighborhood has a land area of 1.6 square miles and a population density of 7,783 people per square mile. Columbia city is a diverse neighborhood with a historic commercial district. The neighborhood is connected by King County Metro bus services and Sound Transit's Link light rail. The economic model reveals the tremendous opportunity to reduce vehicle ownership in Columbia City. There are 7,915 personal vehicles in the neighborhood. A shift to shared mobility transportation modes would reduce the number of personal vehicles by 1,000 to 2,600 (13% to 33%) vehicles. This vehicle reduction would have significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for Columbia City as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Columbia City would:

- Significantly decrease the share of SOV daily trips from 42% to 34%
- Increase transit trip mode share from 4% to 9%
- Increase total daily trips by shared mobility from 1% to 11%

Columbia City would be greatly served by all modes of shared mobility and will experience the benefits of these services including reductions to congestion, parking requirements, curb space optimization, car-free lifestyle, and others.

Policy Implications

Columbia City has many shared characteristics of both Ballard and U-District. All of the policy implications, with exception to the large event item, should be considered for this neighborhood. Columbia City is served directly by the light rail, contains vibrant commercial corridors, and can benefit from expanded shared mobility.

Columbia City also contains a diverse population from both racial and income perspectives. A special lens on equity should be utilized to ensure that everyone in this neighborhood has access to shared mobility modes. The City can create incentives for reduced-fare or more pooling options in this neighborhood in order to achieve a balance for the access to these services. In addition, issues as the unbanked, language barriers, outreach, and others should be considered in identifying equity measures.

Downtown Seattle

Downtown Seattle is the central business district of Seattle and is centrally located within the city. The Downtown Seattle neighborhood has a population of 61,633 people, a land area of 3.2 square miles and a population density of 19,074 people per square mile. Within the neighborhood are many districts for government, finance, shopping, nightlife, and culture. As the primary location for employment in the Puget Sound Region, Downtown Seattle acts as the transit hub for the region. This demonstrates the enormous potential to reduce personal vehicles in Downtown Seattle as determined by the economic model (Chapter 2). The number of personal vehicles in Downtown Seattle is 29,385 and would be reduced by 5,000 to 13,000 (17% to 45%) vehicles through increased shared mobility. This vehicle reduction would have significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for Downtown Seattle as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Downtown Seattle would:

- Significantly decrease the share of SOV daily trips from 30% to 18%
- Increase transit trip mode share from 8% to 15%
- Increase total daily trips by shared mobility from 1% to 14%

Downtown Seattle is predominantly a mix of mid to high-rise office and apartment buildings with first floor commercial uses. There are at least 15 surface parking lots in this area in addition to parking garages and underground parking. The blocks between Pike and Pine Streets, which have the highest portion of retail uses in the area in addition to offices and condominium buildings, could be served by around 100 pick-up and drop-off spaces. The blocks further south on Spring Street would require less dedicated pick-up spaces as they are mainly office buildings and hotels. Should surface parking lots be developed into more productive uses, the number of required shared mobility loading spaces would need to be re-analyzed with the subsequent increased trips to the area.

Land Use	PU/DO spaces needed
Retail Stores/ Retail Center	4
Restaurant	1
Bank	1
Office Building	3
Apartment/Condo	2
Hotel	1
Post Office	1

Land uses not served by pick-up/drop-off (i.e. automotive services, warehousing)

Surface parking

Vacant

Open Space

While many buildings are mixed-use (residential, commercial, and hotels), land use is identified by the parcel's present use classification.
Parcel data source: King County GIS Center

Based on average parking supply ratios for each land use, the parking supply in this area is approximately 42,000 spaces while the required pick-up and drop-off spaces is around 280. All modes of shared mobility would have a tremendous positive impact on Downtown Seattle. It would experience the benefits of these services through reductions to congestion, decreased parking requirements, curb space optimization, car-free lifestyle, and others.

Policy Implications

Downtown Seattle mobility is already a model for U.S. cities. The Commute Trip Reduction Program already sets targets for non-SOV commute modes and provides incentives for transit and alternate modes. In addition, One Center City, a holistic 20-year transportation plan has begun initial stages and will be critical to identify how people will connect and move through this growing employment and population center. Policy considerations, including those discussed in other neighborhoods regarding ROW, land-use, safety, major event planning, equity, and others, is to utilize both of these programs to ensure that Downtown Seattle can continue to grow and connect all residents and visitors in the region.

Finally -- due to the number of residents, visitors, and commuters this area serves -- a minor mode shift could have major implications. This stated, both programmatic policies and nuanced "nudges" should be employed accompanied by a continuous cycle of pilots.

Bellevue

Bellevue is a major commercial and residential center in King County located to the east of Seattle and is bounded by Lake Washington to the west and Lake Sammamish to the east. It is also considered a major hub in many ways, and has a population of approximately 132,268 people and a land area of 31.97

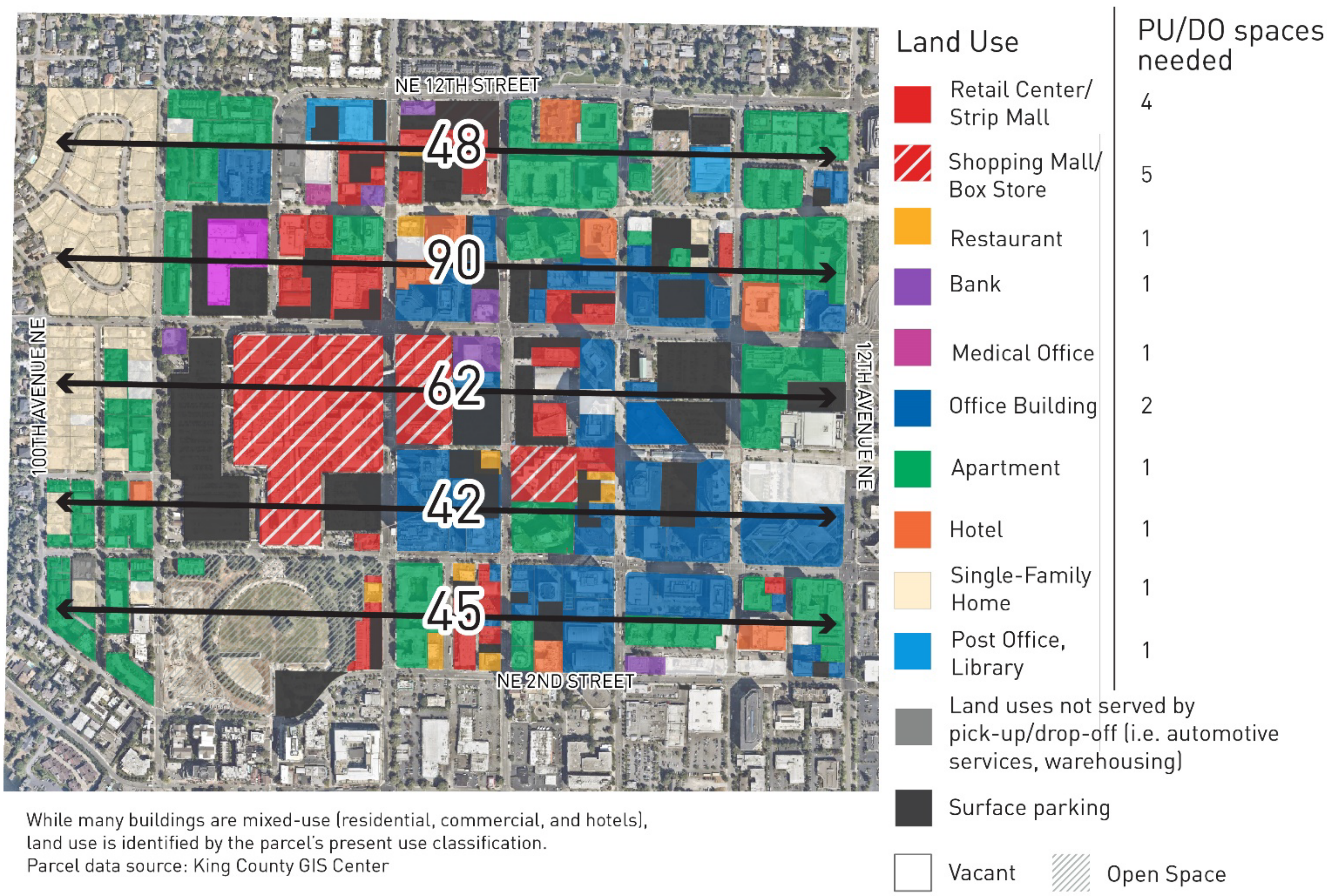
square miles giving it a population density of 4,137 people per square mile. King County Metro and Sound Transit provide transportation services to Bellevue transit hub.

The future travel demand for Bellevue as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Bellevue would:

- Significantly decrease the share of SOV daily trips from 50% to 30%
- Increase transit trip mode share from 3% to 13%
- Increase total daily trips by shared mobility from 1% to 12%

The analysis in Bellevue focused on the Eastgate Neighborhood, which is located on the south side of Bellevue. Bisected by I-90, this area includes a regional shopping center and express transit connection via a major park-n-ride, but is largely surrounded by a disjointed street network. It comprises of a mix of land uses including shopping malls, mid-size office buildings, single-family homes, and apartments. A large amount of surface parking exists, especially near the shopping mall and retail centers or strip malls.

Surface parking dominates much of the landscape in Eastgate. For instance, Bellevue Square Mall alone has a parking lot with more than 1,000 spaces. The spatial analysis shows that with an estimated 384 trips per hour, arrivals and departures to the mall could be accommodated by 5 pick-up and drop-off spaces.



While many buildings are mixed-use (residential, commercial, and hotels), land use is identified by the parcel's present use classification.
Parcel data source: King County GIS Center

This area of Bellevue is composed of a mix of land uses including shopping malls, mid-size office buildings, single-family homes, and apartments. A large amount of surface parking exists, especially near the shopping mall and retail centers or strip malls. Bellevue Square Mall alone has a parking lot with more than 1,000 spaces. The analysis shows that with an estimated 384 trips per hour, arrivals and departures to the mall could be accommodated by 5 pick-up and drop-off spaces.

Land use implications are the largest potential improvement for areas that are (1) built out, (2) well connected to the transit network, and (3) have other regional destinations in proximity to the site. Based on average parking supply ratios for each land use, the parking supply in this area is approximately 28,000 spaces while the required pick-up and drop-off spaces is around 285.

Policy Implications

Similar to Ballard, Eastgate could potentially see a transformation of surface parking to active uses. In addition, major arterials could be optimized if connections to the park-in-ride were improved. Identifying more connections for bikes, transit, and shared mobility would greatly-improve usage of the park-n-ride facility leading an increase to the number of transit riders on both express and local routes. Additionally, the park-n-ride could be transformed into a shared mobility hub that creates space for different connecting modes and prioritizes these modes based on the number of users per trip.

As a result of increased shared mobility, Bellevue will receive benefits that will grow over time and will enable new access to last mile connections. Benefits include reductions to congestion, curb space optimization, car-free lifestyle, and others. Additionally, lower parking requirements would free up land use for denser redevelopment opportunities.

Kent

Kent is a major warehouse and employment center in King County located to the south of Seattle and in near of Sea-TAC airport. Associated with much of the employment opportunities, Kent has a population of approximately 122,620 people and a land area of 28.63 square miles giving it a population density of 4,283 people per square mile. Several large corporations are headquartered in Kent and is one of the largest manufacturing and distribution areas in the United States. Kent is served by King County Metro bus lines and Sound Transit commuter rail. The economic model (Chapter 2) demonstrates that there is meaningful opportunity to reduce auto-ownership. In Kent there are 76,395 personal vehicles. Through increased shared mobility methods, the number of personal vehicles would be decreased by 8,900 to 24,000 (12% to 31%) vehicles. These reductions would have significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for Kent as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Kent would:

- Significantly decrease the share of SOV daily trips from 51% to 36%
- Increase transit trip mode share from 2% to 9%
- Increase total daily trips by shared mobility from 1% to 10%

Kent would receive some benefit from shared mobility especially new last mile connections. Population density, employment density, access to transit, and other factors will limit availability of , carshare, bike share , car share, ridesplitting, and microtransit. Ridesourcing may be a higher valued shared mobility option for Kent as it is the only alternative option for similar mobility as SOV driving. The benefits of these services including reductions to congestion, lower parking requirements, curb space optimization, car-free lifestyle, and others.

Policy Implications

The biggest mobility challenge for Kent is to establish reliable connections to many manufacturing and warehouse jobs at various hours through the multiple work shifts. Several King County Metro routes serve Kent, but it lacks the density for a high-frequency network. Kent would best leverage shared mobility through creating partnerships in the near-term for last-mile connections and airport-bound trips. Models can be found in similar pilots in Pinellas County[50] or SEPTA.[51]

Additionally, the Kent Sounder train station has the opportunity to be a focal point for regional mobility and a shared mobility hub for the City of Kent. The station currently sits in the central commercial area and, combined with more mobility options, could enhance density and mixed use land uses. As future regional transit is expanded and service levels increase, opportunities for last-mile will increase.

Shoreline

Shoreline is a jurisdiction in King County and is located immediately north of Seattle's northern city limits. Though primarily residential it has a similar density to Seattle. Shoreline has a population of approximately 54,254 people and a land area of 11.67 square miles giving it a population density of 4,647 people per square mile. Transit services include King County Metro Transit, Community Transit, and Sound Transit. Our economic model (Chapter 2) demonstrates that there is meaningful opportunity to reduce auto-ownership. In Shoreline there are 37,811 personal vehicles. Through increased shared mobility methods, the number of personal vehicles would be decreased by 4,700 to 12,697 (13% to 34%) vehicles. These reductions would have significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for Shoreline as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Shoreline would:

- Significantly decrease the share of SOV daily trips from 50% to 34%
- Increase transit trip mode share from 2% to 10%
- Increase total daily trips by shared mobility from 1% to 10%

Shoreline has always benefited from close proximity to major employment centers. A big opportunity to strengthen these connections will come along in the next decade due to the Lynwood Link Extension bringing two new light rail stations to Shoreline. In 2023, Shoreline would have a new light rail stations at 145th and 185th streets located just to the east of I5. The City of Shoreline, in coordination with Sound Transit, is currently identifying ways to ensure these connections enhance mobility and land use.

Policy Implications

Similar to recommendations for U-District and Kent, a shared mobility hub around the new stations would encourage more connections to the fixed-route transit network, a higher and better mixed of uses, and enhance mobility overall. The City of Shoreline has responded and is performing new sub-area planning efforts. Metro should continue to encourage that shared mobility connections are identified as a key consideration for this area.

As a result of increased shared mobility and light rail service, Shoreline has the opportunity to transform key sub-areas that will benefit from greater connections, lower parking requirements on new developments, curb space optimization, car-free lifestyle, and others.

Maple Valley

Maple Valley is an exurban bedroom community in King County located to the south east of Seattle at the edge of the Metro Service area. It has a population of approximately 24,040 people and a land area of

50 http://www.psta.net/press/10-2016/directconnect/index.php
51 http://www.septa.org/media/releases/2016/05-25-16a.html

5.72 square miles giving it a population density of 4,202 people per square mile. The area is served by King County Metro and Sound Transit.

The economic model (Chapter 2) demonstrates that there is meaningful opportunity to reduce auto-ownership. In Maple Valley there are 17,079 personal vehicles. Through increased shared mobility methods, the number of personal vehicles would be decreased by 1,700 to 4,600 (10% to 27%) vehicles. These reductions would have significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for Maple Valley as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Maple Valley would:

- Significantly decrease the share of SOV daily trips from 53% to 38%
- Increase transit trip mode share from 1% to 5%
- Increase total daily trips by shared mobility from 0% to 7%

Maple Valley would receive some benefit from decreased SOV and shifts to shared mobility especially new last mile connections. Population density, employment density, access to transit, and other factors will limit availability of , carsharebike share , car share, ridesplitting, and microtransit. Ridesourcing may be a higher valued shared mobility option for Maple Valley as it is the only similar alternative to SOV driving for many trips. The benefits of these services including reductions to lower parking requirements, curb space optimization, car-free lifestyle, and others.

Policy Implications

Maple Valley could pursue subsidized partnerships with shared mobility providers to make connections to the transit network, essentially serving as an extension of the fixed-route network. Currently, it is served by the 164/168 at limited service intervals. Ridesourcing could help fill in the gaps of service, extending the availability of the entire network. Additionally, Maple Valley would be a good candidate for a dynamically-routed microtransit route/dial-a-ride option that would serve the low-density neighborhoods.

Sammamish

Sammamish is a jurisdiction in King County located to the east of Seattle. Bounded by Lake Sammamish to the west with bountiful parks, Sammamish has a population of approximately 49,077 people and a land area of 18.22 square miles giving it a population density of 2,693 people per square mile. There are no freeways within the city limits, however King County Metro and Sound Transit provide transportation services to residents. Our economic model (Chapter 2) demonstrates that there is meaningful opportunity to reduce auto-ownership. In Sammamish there are 33,927 personal vehicles. Through increased shared mobility methods, the number of personal vehicles would be decreased by 2,800 to 7,600 (8% to 22%) vehicles. These reductions would have significant benefits to the available right-of-way and land use in the neighborhood.

The future travel demand for Sammamish as presented in the PSRC Travel Demand Model (Chapter 3) shows a remarkable shift in the travel modes of choice. With a 25% reduction in auto ownership in 2030 Sammamish would:

- Significantly decrease the share of SOV daily trips from 52% to 37%
- Increase transit trip mode share from 1% to 6%
- Increase total daily trips by shared mobility from 1% to 9%

Sammamish would receive some benefit from decreased SOV and shifts to shared mobility especially new last mile connections. Population density, employment density, access to transit, and other factors will limit availability of bike share, car share, ridesplitting, and microtransit. Ridesourcing may be a higher valued shared mobility option for Sammamish as it is the only similar in mobility but alternative to SOV driving for many trips and the enhancement in mobility is valuable in a mobility-scarce atmosphere. The benefits of these services including reductions to congestion, lower parking requirements, curb space optimization, car-free lifestyle. Additionally, people aging in place and low income groups would have increased accessibility to transportation.

Policy Implications

Similar to Maple Valley, Sammamish could pursue subsidized partnerships with shared mobility providers to make connections to the transit network, essentially serving as an extension of the fixed-route network, which currently ends outside of the city limits. Ridesourcing could help fill in the gaps of service, extending the availability of the entire network. Additionally, Maple Valley would be a good candidate for a dynamically-routed microtransit route/dial-a-ride option that would serve the low-density neighborhoods.

Selected Bibliography

The following bibliography is derived from selected chapters of "Shared Mobility: Current Practices and Guiding Principles", an FHWA report written by Susan Shaheen, Adam Cohen, and Ismail Zhody. It contains a collection of references that provide relevant background regarding the state of the shared mobility industry in 2016 and supporting research. For more background, please see report number FHWA-HOP-16-022.

Andersen, M. (2014, November 12). *bikeportland.org*. Retrieved February 9, 2015, from http://bikeportland.org/2014/11/12/car2gos-new-bike-racks-passed-portland-test-113344

Auto Rental News. (2010, June 16). Zipcar Granted Graves Protection. *Auto Rental News*.

Auto Rental News. (2012, January 11). *Legislation OKs Peer-to-Peer Car Sharing in Oregon*. Retrieved from Auto Rental News: http://www.autorentalnews.com/channel/fleet-insurance/news/story/2012/01/peer-to-peer-car-sharing-now-legal-in-oregon.aspx

Badger, E. (2015, January 13). Uber offers cities an olive branch: your valuable trip data. *The Washington Post*.

Bay Area Bike Share. (2015, February 9). Retrieved February 9, 2015, from http://www.bayareabikeshare.com/

Bender, A. (2013, September 10). *PayPal taps Bluetooth for contactless payments*. Retrieved March 7, 2015, from http://www.techworld.com.au/article/526008/paypal_taps_bluetooth_contactless_payments/

Bieszczat, A. (2011). The Taxation of Carsharing: Is Public Policy Consistent with the Public Benefits of Carsharing? . *Chaddick Institute for Metropolitan Development* (p. 23). Chicago: DePaul University.

Bike Arlington. (2012, November). *Arlington Bikeshare Transit Development Plan (TDP)*. Retrieved March 7, 2015, from http://www.bikearlington.com/pages/bikesharing/arlington-bikeshare-transit-development-plan/

Bike Taxi. (2015, December 7). Retrieved from Bike Taxi: http://www.biketaxi.net/

Borecki, N., Buck, D., Chung, P., Happ, P., Kushner, N., Maher, T., Buehler, R. (2012). *Virginia TechCapital Bikeshare Study.* Blacksburg: Virginia Tech.

Business Insurance. (2008, August 31). Vanpools cut costs, increase some risks. *Commuting aid adds to liability exposures*.

California Public Utilities Commission. (2015, April 28). *Transportation Network Companies*. Retrieved from California Public Utilities Commission: http://www.cpuc.ca.gov/PUC/Enforcement/TNC/

Canedo, N. (2014, November 19). Uber executive in New York allegedly used company's 'God View' tool to track journalist. *Syracuse Post-Standard*.

Capital Bikeshare. (2015). *Bank on DC*. Retrieved from Capital Bikeshare: https://www.capitalbikeshare.com/bankondc

Cecil, A. (2015, April 8). *Uber, Lyft, and other rideshare drivers now have insurance options*. Retrieved from Policy Genius: https://www.policygenius.com/blog/uber-lyft-and-other-rideshare-drivers-now-have-insurance-options/

Center for Neighborhood Technology. (2013, August 14). Retrieved February 9, 2015, from http://www.cnt.org/sites/default/files/publications/CNT_35Years.pdf

Chan, N., & Shaheen, S. (2011). Ridesharing in North America: Past, Present, and Future. *Transport Reviews*, 1-20.

City CarShare. (2014, July 15). *A Unique Partnership to Promote Elderly Independence*. Retrieved March 7, 2015, from https://citycarshare.org/newsletters/july-2014-a-unique-partnership-and-more-referral-credits/

City CarShare. (2015). *CommunityShare*. Retrieved March 7, 2015, from https://citycarshare.org/plans-pricing/other-plans/communityshare/

City of Austin. (2009, November 17). *Agreement for Pilot Car Share Program*. Retrieved March 7, 2015, from http://www.austintexas.gov/edims/document.cfm?id=145020

City of Austin. (2014). *AN ORDINANCE DEFINING TRANSPORTATION NETWORK COMPANIES*. Retrieved from City of Austin: http://www.austintexas.gov/edims/document.cfm?id=219353

City of San Jose. (2014, October 10). *San Jose International Airport Commercial Ground Transportation Rules and Regulations*. Retrieved March 7, 2015, from http://www.flysanjose.com/fl/business/gt_permits/gt_rules.pdf

City of Seattle. (2015, January 13). *SDOT Free-Floating Car Sharing Code Revision ORD*.

Costa, J. (2015, February 2). *DMV Threatens Uber, Lyft Operations; California Legislators Address Archaic Interpretation of Old Law*. Retrieved February 26, 2015, from http://www.turlockcitynews.com/news/item/4592-dmv-threatens-uber-lyft-operations-california-legislators-address-archaic-interpretation-of-old-law

Covert, J. (2015, February 27). Uber says it got hacked - over nine months ago. *The New York Post*.

de Looper, C. (2015, August 24). *Uber Testing Bus-Like 'Smart Routes*. Retrieved from Tech Times: http://www.techtimes.com/articles/79084/20150824/uber-testing-bus-smart-routes.htm

Denver BCycle. (2011). 2011 Season Results. https://denver.bcycle.com/docs/librariesprovider34/default-document-library/annual-reports/dbs-2011-annual-report.pdf?sfvrsn=2

Dill, J., Mathez, A., Nathan, M., & Howland, S. (2014). Who Uses Peer-to-Peer Carsharing? An Early Exploration. *94th Annual Meeting of the Transportation Research Board* (p. 20). Washington D.C.: Transportation Research Board.

Fraker, G. (2014). Issues of Risk Related to Shared Mobility. get2kno.

Fleischman, J. (2015, March 4). *John Wayne Airport to Open to Uber, Lyft*. Retrieved March 7, 2015, from http://www.breitbart.com/california/2015/03/04/john-wayne-airport-to-open-to-uber-lyft/

Fried, B. (2015, November 25). *Bike-Share Open Data Standard Clears the Way for Better Trip Planning Apps*. Retrieved from Streets Blog NYC: http://www.streetsblog.org/2015/11/25/bike-share-open-data-standard-clears-the-way-for-better-trip-planning-apps/

Glover, M. (2013, July 2). Citi Bike Floods Streets With Thousands of Uninsured Cyclists. *The Observer*.

Harrington, K. (2016, February 27). Ballot Language Set for May 7 TNC Rules Vote. Retrieved from Building ATX: http://buildingatx.com/2016/02/ballot-language-set-for-may-7-tnc-rules-vote/

Harlow, T. (2015, September 7). *Go-To cards can now be used for both transit and car sharing*. Retrieved from StarTribune: http://www.startribune.com/go-to-cards-can-now-be-used-for-both-transit-and-car-sharing/325183601/

Hirsch, R. (2015, January 27). *USAA Piloting Ridesharing Insurance Coverage for Colorado Members*. Retrieved from USAA: https://communities.usaa.com/t5/Press-Releases/USAA-Piloting-Ridesharing-Insurance-Coverage-for-Colorado/ba-p/56583

Hoge, P. (2015, January 22). California DMV says Uber, Lyft cars must have commercial plates. *San Francisco Business Times*.

Jaffe, E. (2015, August 3). *Uber and Public Transit Are Trying to Get Along*. Retrieved from CityLab: http://www.citylab.com/cityfixer/2015/08/uber-and-public-transit-are-trying-to-get-along/400283/?utm_source=SFTwitter

Kaplan, M. D. (2010, November 14). *smartplanet.com*. Retrieved February 9, 2015, from http://www.smartplanet.com/blog/pure-genius/dc-unveils-countrys-largest-bike-share-program/

Kitsap County Transit. (2013, December 11). Retrieved February 9, 2015, from http://www.kitsaptransit.com/scoot

Koffman, D. (2004). *TCRP Synthesis 53: Operational Experiences with Flexible Transit Services.* Washington, DC: Transportation Research Board of the National Academies

Mann, T. (2013, July 23). The Wall Street Journal. Citi Bike Accidentally Exposes Customer Credit Card Information.

Marich, M. (2015, October 13). *BCycle and RideScout Demonstrate First Use of Smart Phone and Apple Watch to Locate, Unlock and Pay for Bike Share Bike*. Retrieved from Ridescout: http://ridescout.com/2015/10/13/bcycle-bcycle-and-ridescout-demonstrate-first-use-of-smart-phone-and-apple-watch-to-locate-unlock-and-pay-for-bike-share-bike/Millard-Ball, A., Murray, G., Ter Schure, J., and Fox, C. (2005). *Car-Sharing: Where and How It Succeeds.* Retrieved December, 15, 2015, from http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_108.pdf

Martin, E., & Shaheen, S. (2010). *Greenhouse Gas Emission Impacts of Carsharing in North America.* San Jose: Mineta Transportation Institute.

McClatchy Tribune Services. (2013, September 10). *Part-time job growth rapidly outpacing full-time opportunities, statistics show*. Retrieved from The Times-Picayune: http://www.nola.com/business/index.ssf/2013/09/part-time_job_growth_rapidly_o.html

NYC Pedicab Co. (2016, March 7). *Central Park Pedicab Tours FAQs.* Retrieved from NYC Pedicab Co.: http://www.centralparkpedicabs.com/p/faqs.html

New York City Department of Transportation. (n.d.). *NYC Bikeshare Designed By New Yorkers*. Retrieved February 27, 2015, from http://www.nyc.gov/html/dot/downloads/pdf/bike-share-outreach-report.pdf

Pacenti, J. (2014, September 30). Suit Tests Cars2Go Immunity After Car Crash Kills Bar-Hopping Young Woman. *Daily Business Review*.

Packaged Facts. (2015, September 21). *Packaged Facts: 30% of U.S. Consumers Order Online for Same Day Delivery*. Retrieved from PRN Newswire: http://www.prnewswire.com/news-releases/packaged-facts-30-of-us-consumers-order-online-for-same-day-delivery-300145756.html

Pew Research Center. (2014, October). *Mobile Technology Fact Sheet*. Retrieved from Pew Research Center: http://www.pewinternet.org/fact-sheets/mobile-technology-fact-sheet/

Phys.org. (2014, December 16). *Uber targeted by Belgium tax probe*. Retrieved March 7, 2015, from http://phys.org/news/2014-12-uber-belgium-tax-probe.html

Rayle, L., Dai, D., Chan, N., Cervero, R., and Shaheen, S. (2016). "Just A Better Taxi? A Survey-Based Comparison of Taxis, Transit, and Ridesourcing Services in San Francisco," Transport Policy, Volume 45, pp. 168-178.

Rouan, R. (2014, November 9). Car2Go's 2nd year brings on new rules. *The Columbus Dispatch*.

San Francisco Municipal Transportation Agency. (2015, October 19). *SFMTA Proposes New Shuttle Rules.* Retrieved December 15, 2016, from https://www.sfmta.com/about-sfmta/blog/sfmta-proposes-new-shuttle-rules

San Francisco Muncipal Transportation Agency. (2014, January 6). *Mayor Lee and SFMTA Announce Agreement with Commuter Shuttle Providers to Benefit Muni and Overall Transportation Network*. Retrieved February 26, 2015, from http://sfmta.com/news/press-releases/mayor-lee-and-sfmta-announce-agreement-commuter-shuttle-providers-benefit-muni

San Francisco Municipal Transportation Agency. (2013, July). *Car Sharing Policy and Pilot Project*. Retrieved from SFMTA:
https://www.sfmta.com/sites/default/files/projects/SFMTA%20Car%20Sharing%20Policy_MTAB_20130716.pdf

Schaller Consulting. (2006). Taxicab and Livery Crashes in New York City 2004 . New York City.

Segraves, M. (2014, January 13). *Car Share Users Guaranteed Free Parking on D.C. Streets*. Retrieved March 7, 2015, from http://www.nbcwashington.com/news/local/Car-Share-Users-Guaranteed-Free-Parking-on-DC-Streets-240003911.html

Shaheen, S., & Christensen, M. (2015). Shared-Use Mobility: What Does the Future Hold? *Emerging and Innovative Public Transport and Technologies Committee (AP020)* (p. 7). Washington D.C. : Transportation Research Board.

Shaheen, S. A., Cohen, A. P., & Roberts, J. D. (2006). Carsharing in North America: Market Growth, Current Developments, and Future Potential. In *Transportation Research Record: Journal of the Transportation Research Board* (pp. 116-124). Washington, D.C.: Transportation Research Board of the National Academies.

Shaheen, S. A., Mallery, M., & Kingsley, K. (2012). Personal Vehicle Sharing Services in North America. *Research in Transportation Business & Management, Vol. 3*, pp. 71-81.

Shaheen, S. A., Martin, E. W., Cohen, A. P., & Finson, R. S. (2012). *Public Bikesharing in North America: Early Operator and User Understanding.* San José: Mineta Transportation Institute.

Shaheen, S., Martin, E., Chan, N., Cohen, A., & Pogodzinski, M. (2014). Public Bikesharing in North America During A Period of Rapid Expansion: Understanding Business Models, Industry Trends and User Impacts. San Jose: Mineta Transportation Institute.

Shaheen, S., Rodier, C., Murray , G., Cohen, A., & Martin, E. (2010). *Carsharing and Public Parking Policies: Assessing Benefits, Costs, and Best Practices in North America.* San Jose: Mineta Transportation Institute.

Shaheen, S., Shen, D., & Martin, E. (2016). *Understanding Carsharing Risk and Insurance Claims in the United States.* In *Transportation Research Record: Journal of the Transportation Research Board* (*forthcoming*). Washington, D.C.: Transportation Research Board of the National Academies.

Soper, T. (2014, October 20) *uberX, Lyft approved to pick up and drop off passengers at SFO.* Retrieved from http://www.geekwire.com/2014/lyft-approved-pick-drop-passengers-sfo/

Srivastava, S., & Surabhi. (2015, March 2). E-commerce business with 'aggregator models' now to be taxable; Uber, TripAdvisor to be taxed. *The Financial Express*. Retrieved from http://www.financialexpress.com/article/industry/companies/e-commerce-business-with-aggregator-models-now-to-be-taxable-uber-tripadvisor-to-be-taxed/49294/

Soper, T. (2015, February 18). *Flywheel partners with taxi company to create 'FlywheelTaxi,' reaches deal with SFO*. Retrieved from http://www.geekwire.com/2015/flywheel-partners-taxi-company-flywheeltaxi-reaches-deal-sfo/

Staff, B. (2015, April 20). *Birmingham, Alabama, planning e-bike share system.* Retrieved from Bicycle Retailer: http://www.bicycleretailer.com/north-america/2015/04/20/birmingham-alabama-planning-e-bike-share-system#.VdTpWJedpn0

SurveyGizmo. (2010). Nice Ride Subscriber Survey: Survey Report. https://appv3.sgizmo.com/ reportsview/?key=102593-416326-6d13ea0276ea0822c9f59f4411b 6c779

Transportation Research Board. (2015). *Between Public and Private Mobility Examining the Rise of Technology-Enabled Transportation Services.* Retrieved from the Transportation Research Board: http://onlinepubs.trb.org/onlinepubs/sr/sr319.pdf

Velib'. (2012, December 20). *Un service qui plait plus que jamais!*. Retrieved from JCDecaux: http://www.jcdecaux.com/fr/Presse/Communiques/2012/Ve-lib-un-service-qui-plai-t-plus-que-jamais-!

Zauzmer, J. (2015, May 15). *Zipcar loses out to Enterprise on contract to park at Metro stations*. Retrieved from The Washington Post: https://www.washingtonpost.com/news/dr-gridlock/wp/2015/05/15/zipcar-loses-out-to-enterprise-on-contract-to-park-at-metro-stations/