Modeling Car Sharing and Its Impact on Auto Ownership: Evidence from Vancouver and Seattle

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Abstract:

Car sharing is a relatively recent phenomenon but an increasingly important phenomenon in understanding urban household travel behavior. TransLink, the agency responsible for carrying out regional transportation planning for metropolitan Vancouver, British Columbia, and the Puget Sound Regional Council (PSRC) the MPO for metropolitan Seattle, have started investigating this issue. Their recent travel surveys asked the question of all households whether anyone in the household was a member of a car sharing service (not merely using a ride sharing app such as Uber or Lyft). In addition to investigating the impact of car sharing membership on household auto ownership, these surveys provide insight into whether car sharing services lead to a net increase or decrease in motorized travel at the household level.

Two models are investigated in this paper. First, a conventional model of household auto ownership is estimated with car sharing treated as an exogenous input, along with a stand-alone model of car sharing membership. This is followed by a more complex household mobility model that is outlined in the paper (a simultaneous model of household car sharing and auto ownership), which only would make sense in the context of an activity-based model or at least a model with a population synthesizer.

In terms of model results, income is a major predictor of car sharing membership and auto ownership. As expected, the presence of seniors in household and proximity to car sharing lot have the biggest impact on car sharing membership. These variables also impact auto ownership directly, though we find number of workers in the household to play an even larger direct role in auto ownership.

As far as the overall implications emerging from these models, we recommend that auto ownership models be refined to take car sharing membership and ideally transit pass holding into account. In most cases, a series of sequential models will be more feasible than estimating and implementing the simultaneous household mobility model outlined in this paper. Given the strong growth of car sharing in the Pacific Northwest, as well as across North America, we recommend that further research into car sharing membership be carried out, and this of course also means monitoring the growth in usage of traditional car sharing services, as well as the car ride services, which have been transforming the urban transportation system in recent years.

INTRODUCTION AND BACKGROUND ON CAR-SHARING:

Car sharing is a relatively recent phenomenon but an increasingly important phenomenon in understanding urban household travel behavior. It has been a mobility option in North America since the 1990s but only relatively recently become viewed as more than a fringe transportation option worthy of extended study (Shaheen et. al. 2006; Shaheen et. al. 2009).

Despite car-sharing beginning in Europe – and only being introduced to select North American cities in the 1990s – it is estimated that North America has become the major market for car-sharing with just over 50% of car share members. It has been estimated 1 million car-share members in North America against 1.8 million members worldwide as of January 2013 (Shaheen & Cohen 2013; Metro Vancouver 2014).

First, it must be noted that car-sharing is distinct from ride-sharing or ride-sourcing services like Uber or Lyft, which are broadly similar to traditional taxi service, and if they have been modelled at all in regional transportation models, it has been through extending and elaborating the taxi mode in the mode choice sub-model.

In car-sharing, the member borrows a shared car and drives him- or herself. Thus, it is essentially a car rental service, but with (typically) lower variable prices and more convenience, so that a significant number of households consider the option to be a satisfactory substitution for owning a household vehicle. Thus, while car-sharing services facilitate auto trips for households, they also induce households to either shed a car or avoid buying a car in the first place (Martin et. al. 2010; Metro Vancouver 2014). Many researchers contend there is significant potential to reduce regional VKT and associated green-house gases through the expansion of car-sharing services, primarily because participating households substitute transit or active transportation modes for the majority of their travel, even if they occasionally are facilitated in making auto trips (Shaheen et. al. 2006; Zhou & Kockelman 2011). In the field of travel demand research, car-sharing is considered potentially disruptive, since 0 auto households that would traditionally be considered transit-captive households may actually have regular access to a vehicle (Petersen & Darwiche 2013).

A short digression on two-way vs. one-way car-sharing may be in order. The first wave of car-sharing companies in North America was comprised of two-way car sharing in which the car is returned where it is picked up (ZipCar, Modo, Autoshare). Peer-to-peer car-sharing (facilitated by companies such as Turo and Getaround), while certainly disruptive in a number of ways, is still two-way car-sharing, as the car owner will expect that the loaned car eventually will make its way back home (Hampshire & Gaites, 2011). One-way car sharing means that the car can be dropped off anywhere within the zone, with some restrictions on metered parking spots and some restricted zones, often in central business districts (Nourinejad & Roorda 2015). Car2Go operates this type of service. Some studies have suggested that the flexibility of one-way car-sharing services leads to even higher rates of car reduction and consequently higher environmental benefits (Firnkorn & Müller 2011; Jorge et al 2015). What is certainly true is that one-way car-sharing has the potential to complicate tour-based modelling, where one of the main features was that tours had mode integrity (as opposed to trip-based modelling that lacked a mechanism to enforce consistency), though it remains to be seen if the scale of the issue will grow to the point that the complex activity-based models must take one-way car-sharing into account (Petersen & Darwiche 2013).

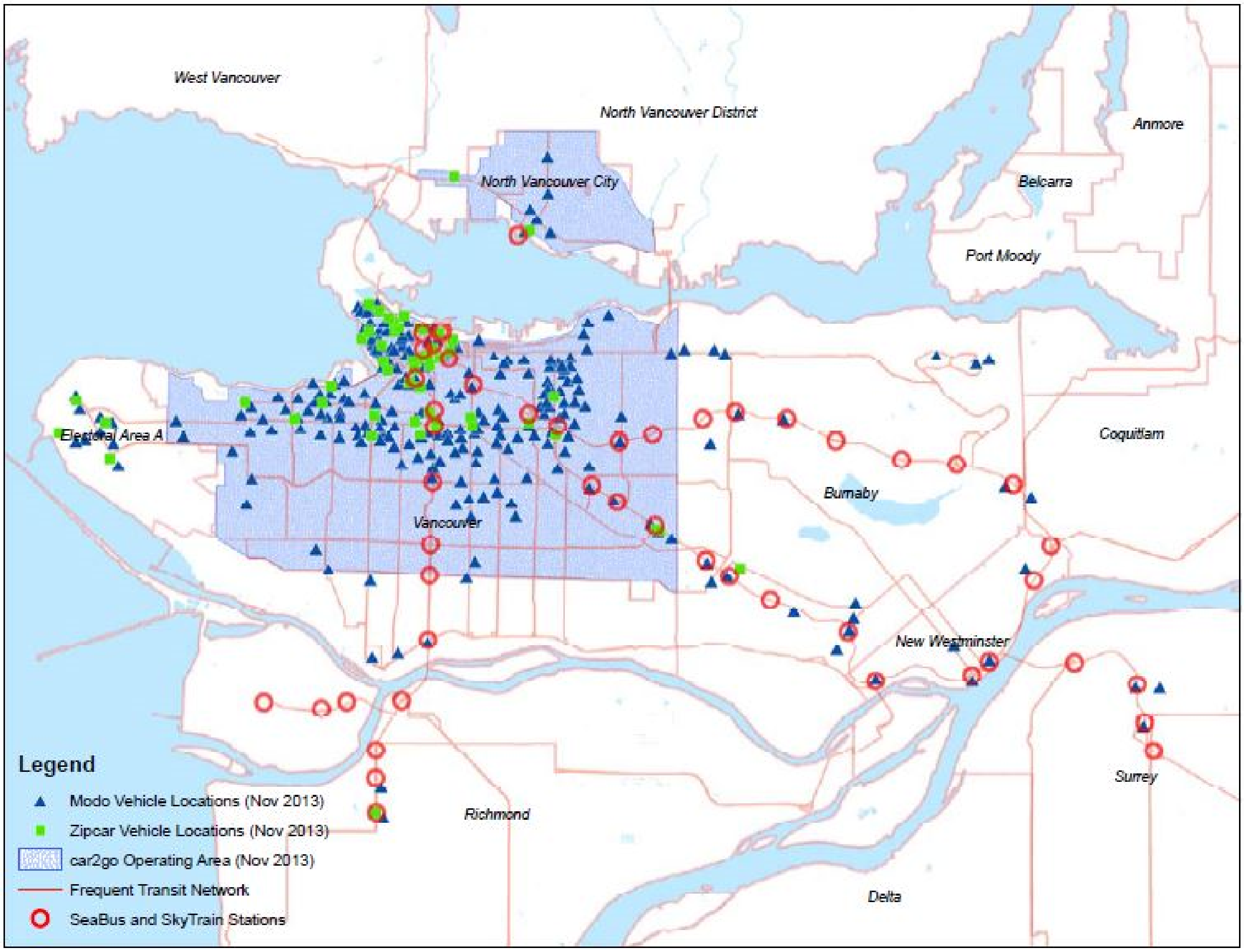
The main issue for this research is that the cars available to facilitate one-way car-sharing are much harder to locate in space, since they may be dropped off anywhere within the zone. Thus, a researcher must either treat the entire car-share zone as having the potential to support car-sharing (the approach taken in this paper) or devise a model to predict the location of these cars at various times of the day (Kortum & Machemehl 2012). The primary issue is that there is a mismatch between the geographic specificity of two-way and one-way car-sharing in terms of predicting vehicle availability, though as will be observed, the models presented in this paper do not currently incorporate a great deal of geographic refinement.

REGIONAL CONTEXT:

Car-sharing has matured in Seattle and Vancouver, making them valuable sites for research. Both cities have two-way and one-way car-sharing services. In fact, one of the first car-share programs in the U.S. was Flexcar in Seattle, which was later acquired by ZipCar. ZipCar and Car2Go operate in both cities, largely concentrated in the urban core (see **Figure 1**, **Figure 4**, **Figure 2** and especially **Figure** 3, which shows the concentration of ZipCar lots in downtown Seattle). However, Car2Go has expanded to North Vancouver (in **Figure 1** the Car2Go zones are shaded in blue). Vancouver has a second two-way car-sharing service (Modo), which incidentally has expanded further into the suburbs than either ZipCar or Car2Go, often by locating their lot near a SkyTrain station as one method to address the first-mile/last-mile issue and still be viewed as supportive of regional transit (Sturges 2011; Friedrich & Noekel 2015). The three services have a combined fleet of just under 1000 cars (see **Table 1**) and have reasonably high visibility throughout Vancouver. Joining a car-share program is no longer viewed as a fringe activity.

In addition to ZipCar and Car2Go, Seattle has Hertz 24/7, which is a bit of hybrid car-sharing system. It allows cars and particularly trucks to be rented at one of 35 locations and dropped off to any other location, so it is not as constrained as two-way car-sharing, but it lacks the true flexibility of a one-way system where the vehicle may be dropped off essentially anywhere within the zone. There does not appear to be as thorough an analysis of the different car-share options in Seattle as there is for Vancouver, though the city of Seattle does survey the members of free-floating car-share services (i.e. Car2Go) as it was one pre-condition for allowing the service to expand its boundaries in Seattle, as well as providing preferential parking treatment to Car2Go vehicles (Seattle Department of Transportation 2014). In 2013, there were almost 35,000 Car2Go members and 500 vehicles. The membership has continued to grow and has been reported as nearly 65,000 as of 2016.

The existing car-sharing services do seem more geographically constrained in metropolitan Seattle compared to metropolitan Vancouver, where service is leaping over suburban boundaries. ZipCar does not provide any car-share lots at Sea-Tac Airport, though Hertz 24/7 does. Car2Go has not expanded beyond Seattle's boundaries (see **Figure 4**), while ZipCar does have a few car lots in Bellevue, Renton, and Renton (see **Figure 2**). ZipCar has a total of 2 lots in Tacoma, compared with over 350 cars located in ZipCar lots in Seattle.



Source: Metro Vancouver Car Share Study 2014

Figure 1: Car-Share locations in Metro Vancouver

Table 1: Details of Car-share Services in Metro Vancouver

	Modo	Zipcar	car2go
Locations and Vehicles	303 vehicles, 245 locations	128 vehicles, 53 locations	550 vehicles, no fixed locations
Operating Areas	Vehicles located in Vancouver, UBC, City of North Vancouver, West Vancouver, Richmond, Burnaby, New Westminster, Coquitlam, Surrey	Vehicles located in Vancouver, UBC, City of North Vancouver, Richmond, SFU Burnaby	Most of Vancouver, UBC, City of North Vancouver, parts of District of North Vancouver, Kwantlen University campuses in Richmond, Surrey, and Langley City
Membership	7,897 individual drivers; 1,667 business-only drivers	Not disclosed	7,400 (interpolated from disclosed data in May 2013, January 2014, and April 2014)
Individual Membership Fees	Co-op membership: One-time $500 refundable shares purchase and $20 registration fee Casual membership: $5 monthly fee and $20 registration fee	Occasional Driving Plan: $25 one-time non-refundable application fee and $65 annual fee Monthly Driving Plan and Extra Value Plan: $25 one-time non-refundable application fee	$35 one-time registration fee

Source: Metro Vancouver Car Share Study 2014

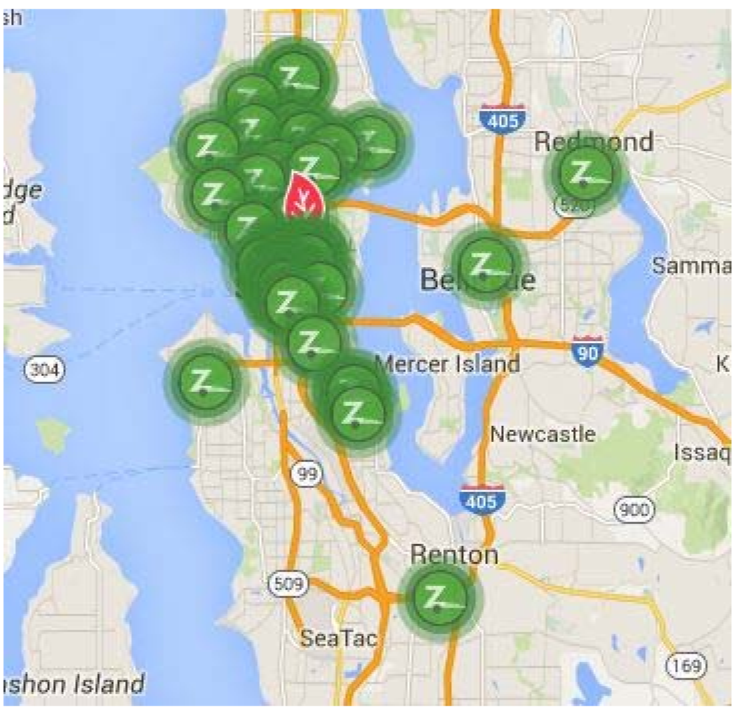


Figure 2: ZipCar locations in Metro Seattle

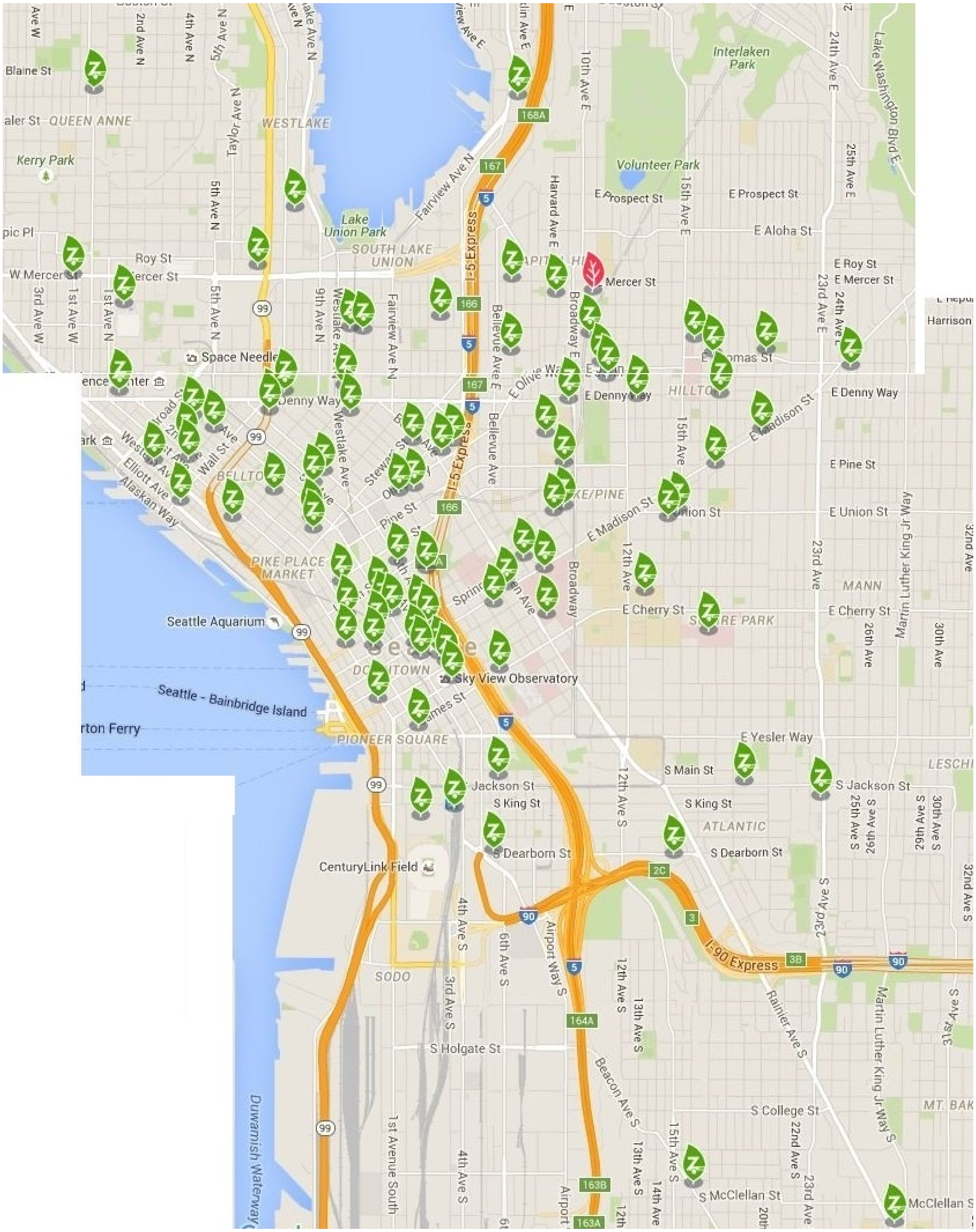


Figure 3: ZipCar lot locations in Central Seattle

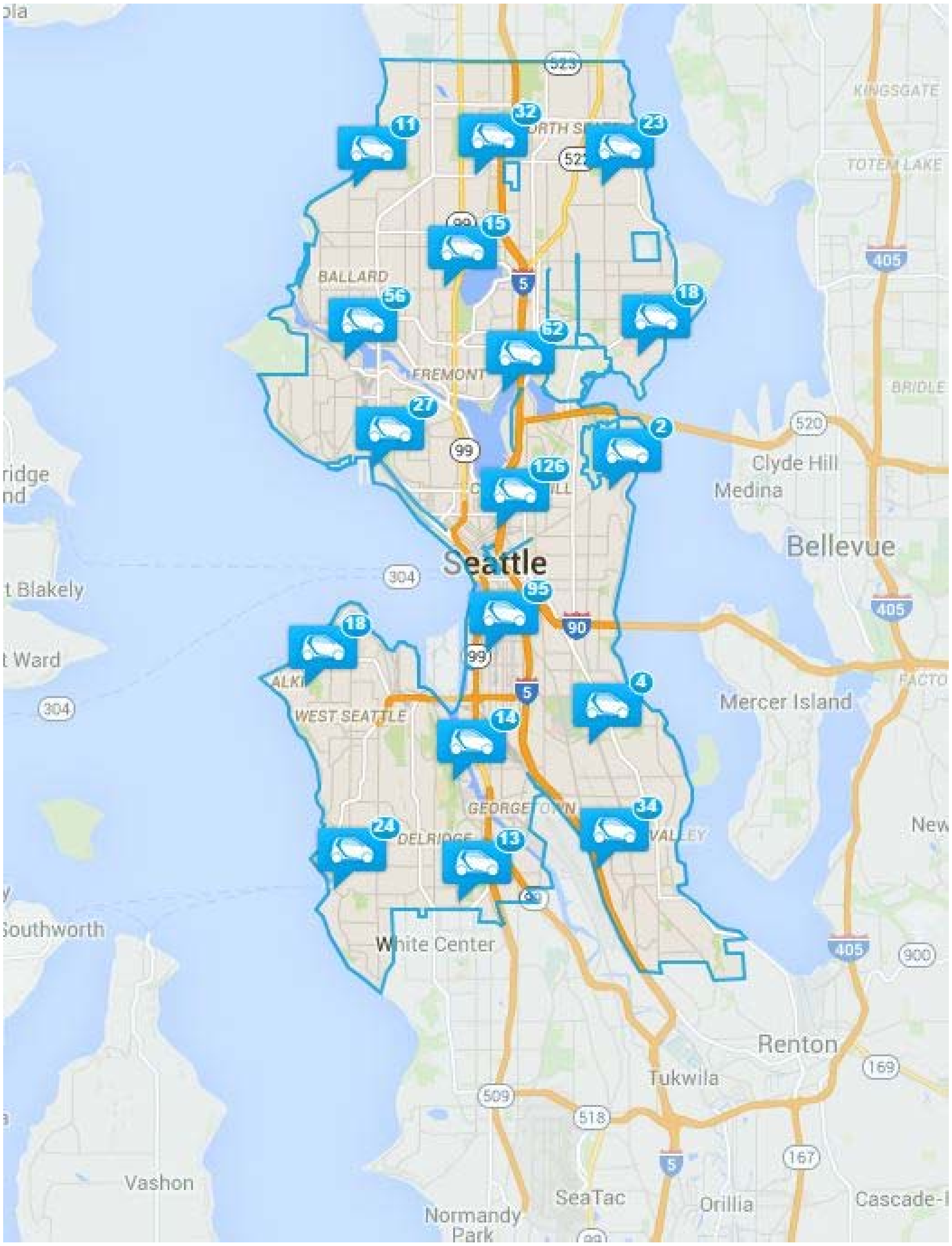


Figure 4: Car2Go Zone in Seattle

LITERATURE REVIEW:

The emphasis in this research project is on viewing car ownership as one mobility strategy undertaken at the household level, which means that it may be substitutable for car-sharing membership (by one or more household members). This was the general approach taken by Kai Axhausen and fellow researchers from Europe working from the Mobidrive data and other longer-term panel data (Scott & Axhausen 2006; Beige & Axhausen, 2008; Kowald et al 2016).

Not surprisingly given the higher profile transit has in Europe, transit pass holding was also included as a “mobility tool” in many of these models (Scott & Axhausen 2006), as well as in some North American models (McElroy 2009; Vovsha & Petersen 2009; Fatmi et al 2014). While generally considered ubiquitous in North America (and thus not worth modelling), driver license holding has occasionally been included as part of the alternative set (Fatmi et al 2014; Kowald et al 2016), rather than as an exogenous variable, which is more typical (Anowar et al 2015).

Land use variables, such as intersection density (and walkability more generally), land use mix and presence of non-motorised facilities have frequently been incorporated into auto ownership models (Potoglou & Kanaroglou 2008; Anowar et al. 2014). Recent advances have included more granularity in the measurement of land use variables, as well as taking into account the proximity of car-share lots (Petersen & Darwiche 2012).

The availability of free parking at a trip destination, particularly when provided for by the employer (and thus is essentially guaranteed), has long been recognized as a major driver of commute model share (Hess 2001; Washbrook et al 2006), but free parking at the destination may also contribute to decisions about auto ownership (Vovsha & Petersen 2009). Increasingly, free parking on the residential end has also been incorporated into auto ownership models (Senbil et al 2009; Guo 2013a; Guo 2013b.)

OUTLINE OF RESEARCH:

Two models are investigated in this paper. First, a conventional model of household auto ownership is estimated with car sharing treated as an exogenous input, along with a stand-alone model of car sharing membership. This is followed by a simultaneous model of household car sharing membership and auto ownership, which requires detailed information about household composition, which only would make sense in the context of an activity-based model or at least a model with a population synthesizer.

One major advance of this research is that it tries to capture the impact of car-sharing as observed among the general population of a metropolitan region, unlike the vast majority of research on car-sharing, which only surveyed existing car-share members. While this is an understandable approach, given that it would have been difficult to observe sufficient car-share members in the early days when there were only early adopters, these surveys cannot answer whether the general population will repeat the experience of early adopters (in terms of numbers of cars shed, for example). Now that car-sharing is a reasonably mature transportation option, it is appropriate to probe whether the impacts are sufficiently large to register in transport models that cover an entire metropolitan region. It should be said that even this research cannot answer unambiguously questions on whether the “late adopters” will behave similarly to households that have already joined car sharing services or whether car-sharing can successfully penetrate the suburbs. This is a concern with practical consequences, since the auto ownership models that follow are designed so that they could supplement or even replace existing auto ownership models, but forecasting some of the new variables required as inputs will be a challenge.

DATA SOURCES:

As mentioned in the previous section, asking all households in region about car-sharing membership gives a much better picture of the true regional impact than asking car-share members only, which inflates its role in the transportation system. TransLink, the agency responsible for carrying out regional transportation planning for metropolitan Vancouver, British Columbia, and the Puget Sound Regional Council (PSRC) the MPO for metropolitan Seattle, have started investigating the regional impact of car-sharing. Their recent travel surveys asked the question of all households whether anyone in the household was a member of a car sharing service (not merely using a ride sharing app such as Uber or Lyft).

In addition to investigating the impact of car sharing membership on household auto ownership, both surveys asked about free or discounted parking. Unfortunately, the two surveys did not ask the questions in a manner that could be easily reconciled. TransLink asked about free parking availability at the home location, and this was not asked by PSRC. Instead, PSRC asked whether the primary employer provided free or subsidized parking, and just as importantly, asked whether the benefits were offered but not used by the respondent. Many travel surveys ask about free parking at work, but only if the typical commute is made by auto mode, which misses out on the (admittedly relatively small) group of workers who forego this benefit. In addition, PSRC also asked if the employer or school offered a transit benefit, again asking about availability of the benefit even of non-transit users.[1]

There are a few shortcomings in the PSRC data. One issue was that while they did ask whether individuals held ORCA cards, they did not probe whether these were bought as monthly passes or pay-as-you-go cards. Consequently, the ORCA users were not distinguishable from the general population of transit users, and we were not able to include transit pass as a mobility tool alternative in the models.[2] A slightly different issue arises from the fact that these really were treated as pilot studies without a fixed sampling frame, thus there is some selection bias in terms of selection bias. The results can be taken as indicative of conditions in the region but not fully representative of the region. Given that our research was exploratory (and partly designed to prove asking questions about car-sharing was worth incorporating into travel surveys in the first place), this was deemed an acceptable limitation.

An earlier pilot survey in 2014 asked about the use of car-sharing apps and whether the respondent considered a car share car to be their regular vehicle, whereas the 2015 pilot asked directly about car-sharing membership. The change in methodology led to almost 3 times as many reported car-share members in 2015. Thus, the 2014 questionnaire, while not necessarily designed this way, captures early adopter and very active users of car-share services, whereas the 2015 survey captured more passive members as well.

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[1] Both TransLink and PSRC have looked into updating their surveys to fill in this missing data, though PSRC appears to have more flexibility in terms of adding new questions to their on-line survey, with the next major survey scheduled for 2017. One encouraging sign for researchers is that Metro in Portland, OR will take advantage of work done on both surveys while designing their next household travel survey, currently scheduled for 2019 or 2020 (private communications with staff of all three agencies).

[2] Seattle does have a transit pass for university students (the U-Pass or Husky Pass), but university students are typically not well captured in travel surveys.

While outside this project's scope, it would be worth running a comparative analysis of the two groups, as the majority of the late adopters will likely be closer to the characteristics of the broader group from 2015 than the more active users identified in 2014. This study restricted the analysis to the 2015 Travel Survey. In terms of sample size, there were 4786 individuals in 2419 distinct households in the 2015 PSRC Travel Survey.

TransLink had a somewhat similar experience with their 2014-2015 pilot study. This was a much smaller survey than TransLink typically administers, but it was repeated every three months for 15 months. It was primarily aimed at capturing seasonal variation, although it was also used to field test questions for inclusion in future travel surveys. In the first two waves (of five), there was probing for car-membership if an individual from a 0 car household made an auto (drive) trip, but there was not a question asking whether anyone in the household was a member of a car-sharing service, so only a very small number of car-share members were observed in the data. For the last three waves of the survey, car-sharing membership was asked. Unfortunately for this study, this information about car-sharing was not transmitted to TransLink (or the study authors) in the initial round of data from the survey firm.[3] Consequently, any further statistics and the models in the paper are all based on the 2015 PSRC data.

MODEL 1 (SEPARATE AUTO OWNERSHIP AND CAR-SHARE MEMBERSHIP MODELS) RESULTS:

The first step was to develop a conventional auto ownership model. The survey was analysed to ensure that some of the typical variables had the expected signs. **Table 2** indicates that automobile ownership generally increases with income, which is a typical finding. In addition, urban households own fewer autos when controlling for income, which is also in line with previous research. The most surprising finding was the preponderance of high income households, particularly urban ones, to have car-share membership.[4] There is presumably interplay between income and the ability to pay an additional membership fee, but potentially higher education levels, environmental attitudes and a willingness to be an early adopter.

Table 2: Household income and household location characteristics

Home location	Household Income	Autos in HH	Car share membership
Urban	Low	0.7	7%
Urban	Medium	1.3	8%
Urban	High	1.7	19%
Non-urban	Low	1.1	0%
Non-urban	Medium	1.8	1%
Non-urban	High	2.3	5%

Source: PSRC 2015 Travel Survey

[3] This effectively means that the authors will be required to wait on the data release in order to estimate models from the Vancouver data, but this should certainly be achievable before the TAC conference.
[4] The 19% rate of car-sharing membership for high income urban households does seem on the high side, and future research will include an investigation of whether this finding is truly representative of the region.

The models that were generated are reported in **Table 3**. The alternatives were 0 auto, 1 auto, 2 autos and 3+ autos owned by each household. The model structure was a multinomial logit (MNL).

As expected, larger households and households with children and/or teens tend to have 2 or 3 autos. One somewhat surprising finding is that seniors in the household had a negative impact on 0 and 1 auto households, meaning that seniors were generally in households with 2 or 3 cars. An even stronger, but more typical, finding is that 2 or more workers in the household tend to lead to 2 or 3+ auto in the household.

Household income is a strong predictor of auto ownership, with low income households much more likely to be 0 auto households or more likely to be 1 auto households and high income households being more likely to be 2 or 3+ auto households, above and beyond the impact of worker.

If the household is located in an urban area (in this case Seattle or Tacoma), there is an increased likelihood of being a 0 car household. Other land use variables were tested as well, though it should be noted that the geographic specificity is not particularly high. The land use variables were calculated at the zip code level. This is an area for future refinement. Intersection density is a measure of the number of street intersections per square kilometer, and it is considered a proxy for walkability. As expected, as intersection density increases, the likelihood of being a 0 or 1 car household increases.

Occasionally, in this type of analysis the negative results are just as interesting as the positive ones. We were expecting that parking benefits (at typical work location) for at least one person in the household would be meaningful and increase the likelihood of 2 or 3+ car ownership, but the variable was not statistically significant. It may be that this is simply too diffuse an incentive to have a measurable impact on household auto ownership, though it almost certainly will have an impact on mode choice. If it becomes available in the next PSRC survey, we will definitely test free residential parking, which we hypothesize will have a stronger impact on additional vehicles in the household. Instead of parking benefits, the availability of employer-provided transit benefits has a strong impact on increasing the likelihood of 0 auto ownership and a somewhat weaker impact on 1 car ownership.[5]

Finally, following Petersen & Darwiche (2012), we included proximity to a car-share lot, which in this analysis included being within the Seattle Car2Go zone (nearly all the Seattle zip codes qualified) or being in the same zip code as a ZipCar parking lot. This had a moderate impact on increasing the likelihood of being a 1 car household. This research and added car-sharing membership (rather than mere proximity) to the car ownership model.

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[5] This does raise the issue of having to forecast the provision of these benefit variables. While this could be generated through a bid-rent model (where the employers are agents just as much as the workers), there are other more straight-forward approaches, such as incorporating transit (and parking) benefits into a long-term employment location decision model.

Table 3: Household car ownership model specifications

		Car Model1		Car Model2	
Initial likelihood		-3355.94		-3355.94	
Final likelihood		-2270.45		-2289.04	
Rho-Squared		0.324		0.318	
		coeff.	t-ratio	coeff.	t-ratio
Alt. specific terms	1 auto	4.05	13.2	3.97	13.4
	2 auto	3.86	11.9	3.84	12.3
	3 auto	2.75	8.3	2.73	8.5
Household characteristics	HH size 3+, 2 cars	0.83	4.1	0.81	4.0
	HH size 3+, 3+ cars	1.97	12.0	1.95	11.9
	children in HH, 2 cars	1.22	7.2	1.22	7.2
	teen in HH, 3+ car	0.64	3.0	0.65	3.0
	senior in HH - 0 car	-0.79	-3.2	-0.87	-3.5
	senior in HH - 1 car	-1.07	-7.5	-1.07	-7.5
	2+ worker - 2 auto	1.57	10.7	1.52	10.5
	2+ worker - 3+ auto	1.98	12.2	1.92	12.0
HH income impacts	low inc. - 0 auto	3.93	15.2	3.77	15.3
	low inc. - 1 auto	1.61	11.0	1.60	11.0
	high inc - 2 car	1.28	7.6	1.17	7.2
	high inc - 3+ car	1.74	9.6	1.63	9.3
Land use impacts	urban HH - 0 car	0.97	4.1	1.00	4.2
	intersection density - 0 car	0.03	5.3	0.03	6.2
	intersection density - 1 car	0.02	5.4	0.02	5.8
Mobilty tool impacts	transit benefits -0 car	0.97	3.9	1.10	4.5
	transit benefits -1 car	0.28	2.0	0.34	2.4
	proximity share lot - 1 car	0.46	2.8	0.48	2.9
	car-share membership - 0 car	2.56	6.2		
	car-share membership - 1 car	1.28	4.1		

The only substantial difference between Model 1 and Model 2 of the auto ownership model was that the car-sharing membership status of the household was included as an exogenous variable, i.e. the car-sharing membership status was known for each household prior to the start of the auto ownership model. Car-sharing membership has a strong positive impact on the 0 auto alternative (2.56), almost exactly twice the impact on the 1 auto alternative (1.28), which corresponds to expectations. While it would be too strong to say the household auto ownership model is mis-specified when car-sharing membership variables are omitted (run7), the model with them (run 6b) included is clearly preferable.

If the car-sharing membership is included in the model specifications, then car-sharing membership must itself be modelled. **Table 4** presents a very simple binary model. In this case, no car-sharing membership was the reference case and all coefficients are applied to the case where the household does have a car-sharing membership.

High income increases the likelihood of holding such a membership, as does proximity to a car-share lot, the preponderance of non-motorized facilities,[6] if someone in the household has access to transit benefits, or if there are 3+ workers in the household (admittedly a very rare case).[7] If there were 2 or more ZipCar lots in the home zip code, this increased car sharing propensity slightly, as did living in Seattle or Tacoma. Having at least one senior in the household reduced the likelihood of being a car-sharing household.

Table 4: Household car-share membership model specificatons

	Car sharing model	
Initial likelihood	-1677.97	
Final likelihood	-366.31	
Rho-Squared	0.78	
	coeff.	t-ratio
car-share bias term	-5.15	-18.0
med income HH	0.36	4.2
high income HH	1.09	4.2
senior in HH	-1.57	-3.2
3+ workers in HH	0.72	2.1
transit-benefits	0.87	4.0
urban HH	0.37	2.0
non-motorized facility	1.36	2.5
proximity to share lot	1.41	4.1
over 2 ZipCar lots nearby	0.37	2.0

However, the primary drawback of this approach is that car-share membership is clearly a mobility tool, and in many households this decision would be chosen in conjunction with the auto ownership decision. Thus, a simultaneous model was desirable, which led to model 2.

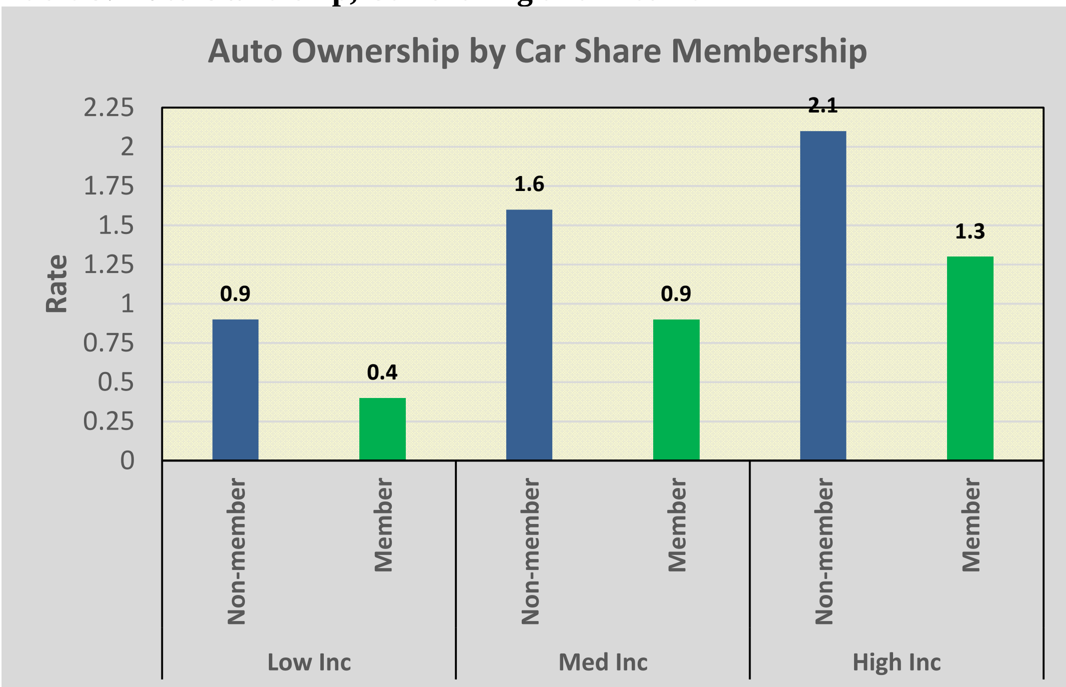
[6] This variable actually measures the ratio of non-motorized facilities (quarter mile buffer) to total area. The average value was 0.26 (or 26% of the zone), so presumably quite a few of these facilities were either shared bike lanes or sidewalks.

[7] Availability of driver's licence (or number of licences held by household members) was considered, but this was not a meaningful variable in Seattle. Only 2.8% of non-urban households lacked a member with a valid driver's licence, and this increased only to 3.7% in urban areas.

MODEL 2 (COMBINED AUTO OWNERSHIP AND CAR-SHARE MEMBERSHIP MODELS) RESULTS:

A preliminary examination of the data suggests a very strong interaction between income and car-sharing to influence auto ownership (see **Table 5**). This suggested a strong possibility of success. The variables considered for inclusion were largely the same as in the separate models.

Table 5: Auto Ownership, Car-sharing and Income



Source: PSRC 2015 Travel Survey

Quite a number of nested logit structures were attempted, but only two were statistically valid. **Figure 5** shows the structure for Combined Model 1, while **Figure 6** shows the structure for Combined Model 2. Both have an attractive conceptual integrity. Household mobility is measured not solely as auto ownership, but auto ownership combined with car-sharing. Thus, a 1 auto household without car-sharing membership drops to a lower mobility category than a household with 1 auto and car-sharing membership. The same holds true in Model run 7 where a 2 car household with car-sharing jumps to the highest mobility category. While the two models returned very similar results, Model run 70 produces slightly improved likelihood results, and it is the more conceptually appealing model as well.

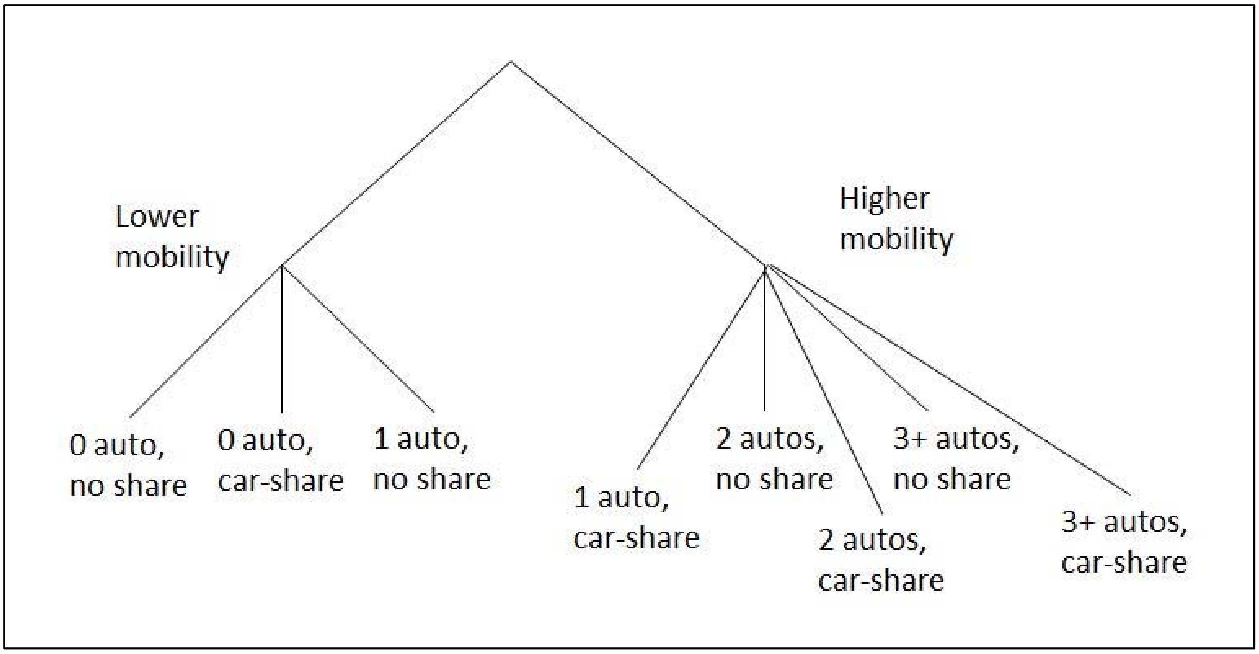


Figure 5: Structure of Combined Model 1

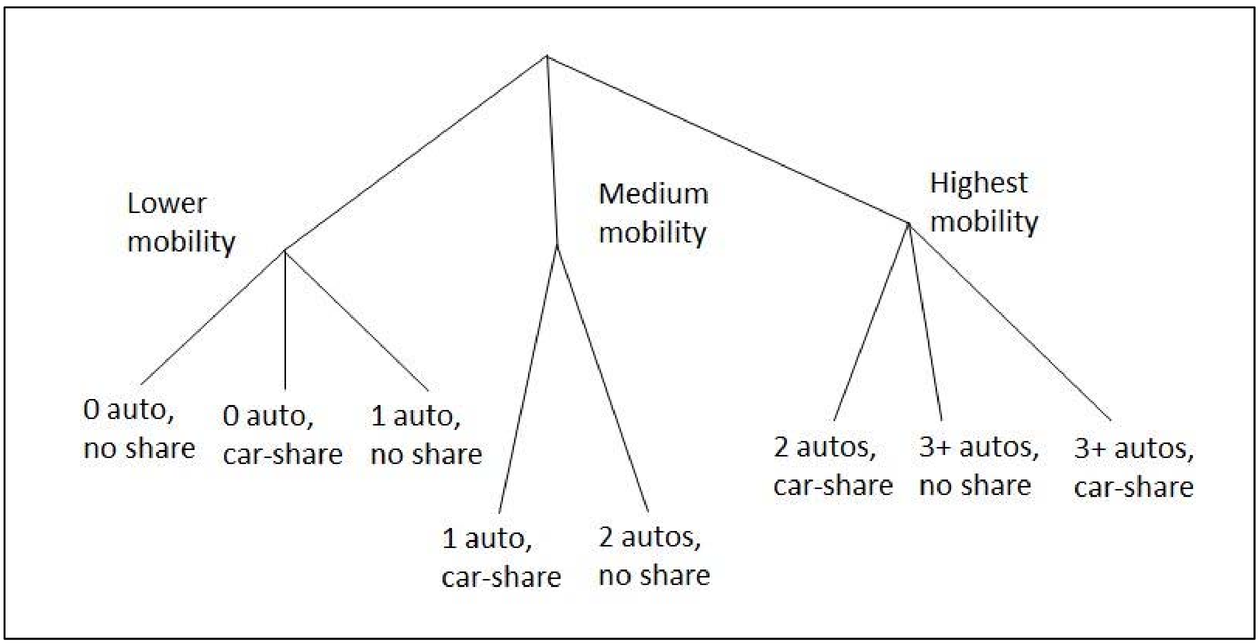


Figure 6: Structure of Combined Model 2

Table 6: Household car ownership/car-share membership model specificatons

		Combined Model 1		Combined Model 2	
Initial likelihood		-5033.91		-5033.91	
Final likelihood		-2636.20		-2636.77	
Rho-Squared		0.476		0.476	
		coeff.	t-ratio	coeff.	t-ratio
nesting parameter (theta)		0.84	6.9	0.96	6.7
Alt. specific terms	1-car no-share	4.83	11.9	4.77	11.9
	2-car no-share	5.08	11.4	5.00	11.0
	3+-car no-share	4.08	9.3	4.16	9.0
	0-car car-share	-2.33	-3.4	-2.35	-3.5
	1-car car-share	-1.57	-1.9	-1.47	-1.8
	2-car car-share	-0.51	-0.8	-0.42	-0.6
	3+-car car-share	-1.07	-1.6	-0.85	-1.3
Household characteristics	HH size 3+, 2 cars no-share	0.77	3.2	0.73	2.8
	HH size 3+, 2 cars car-share	1.19	2.6	1.12	2.4
	HH size 3+, 3+ cars	2.19	6.3	1.93	6.6
	children in HH, 2 cars	1.51	5.3	1.31	6.8
	teen in HH, 0 car no-share	1.50	3.1	1.54	3.2
	teen in HH, 3+ cars	0.79	2.9	0.69	3.1
	senior in 1 person HH - 0 car	0.50	2.0	0.48	1.9
	senior in 2+ person HH - 0 car	-2.10	-3.3	-1.93	-3.1
	senior in 2+ person HH - 1 car	-1.85	-5.7	-1.64	-5.6
	senior in HH - 0 car car-share	-2.24	-1.9	-2.25	-2.0
	senior in HH - 1 car car-share	-1.91	-2.1	-1.86	-2.0
	2+ workers, 2+ cars no-share	1.99	6.6	1.76	6.4
	2+ workers, 2+ cars car-share	2.96	6.0	2.75	5.7
HH income impa	low inc - 0 car	4.55	9.2	4.21	8.9
	low inc - 1 car	2.14	5.6	1.85	5.1
	high inc - 3+ car	0.96	4.9	0.80	6.9
	not low inc - sharing (0/1 car)	1.76	4.3	1.59	3.9
	high inc - sharing (2+car)	1.54	4.1	1.37	4.1
Land use impacts	urban HH - 0 car no-share	1.80	5.3	1.66	5.6
	urban HH - 0 car car-share	1.35	5.3	1.24	5.6
	urban HH - 1 car no-share	0.94	3.6	0.81	3.9
	urban HH - 1 car car-share	2.38	3.3	2.23	3.2
	urban HH - 2 car	0.79	4.1	0.68	4.8
	non-motorized facility index - 0 car car-share	3.00	2.7	3.01	2.7
	intersection density - 0/1 car	0.01	2.6	0.01	2.6
	land mix - 0 car no-share	3.03	3.9	2.88	3.8
	land mix - 1 car no-share	1.14	2.4	1.00	2.3
Mobilty tool impacts	transit benefits - 0 car no-share	1.26	4.4	1.17	4.3
	transit benefits - 0 car car-share & 1 car (all)	0.46	2.6	0.39	2.5
	proximity share lot -0 car car-share	1.80	2.9	1.78	2.9
	proximity share lot - 1 car car-share	2.76	4.3	2.79	4.4
	proximity share lot - 2 cars car-share	1.47	3.8	1.49	3.9
	proximity share lot - 3+ car car-share	1.34	2.9	1.26	2.8

Table 6 presents the results for the two models. As many of the relationships are the same as the stand-alone car ownership model, the results will not be explained in great detail. In general, large households tend to favor higher mobility options relative to lower ones. Having children in household has positive utility to two vehicles - makes sense since one parent needs to pick up and drop off children and the marginal benefit of having more than two is very small , by same token having a teen (likely has driving license) favors higher mobility, i.e. 3+. One of the more anomalous findings was that presence of teen in the household increased the likelihood of being a 0 car household without car sharing membership. This finding will be probed more extensively when the 2017 PSRC data becomes available.

In general, if a senior is present in the household the household favors 2 or more autos. This most likely arises from the sampling issues where urban households were over-represented, so when senior were present then this was a multi-generational household with higher mobility needs. While all interactions with presence of seniors and household size were not probed, the models did show that 1 person households comprised of a senior did have a positive impact on 0 auto households. What is clear is that households with seniors are not early adopters, since there is a very large negative term for having a senior in the household and being part of a car share program if there are 0 or 1 cars in the household.

Higher numbers of workers (2+) favors higher mobility, and marginally favors car-share membership alternatives. As expected, lower income households have high utility towards low mobility. High income groups who choose lower levels of auto ownership are more likely to be a car share member as well. (This is almost certainly tied to a "taste" for environmentalism, but we decided not to explore such latent categories in this analysis.) On the other hand, there is also a reasonably-sized group of high income households who are also car-share members, leading to a positive on this term.

Intersection density correlates positively with lower mobility alternatives, which makes sense, as the denser environment encourages use of other modes, such as active and transit modes. Land use mix takes a 1.0 if all six categories of land uses are evenly balanced. While this ranged from 0.02 to 0.76, and the average value for the variable was 0.38. Zones with more mixed land use were supportive of car-share membership, particularly for 0 and 1 car households.

As expected, proximity to car share lot will in general encourage lower levels of vehicle ownership/mobility. While the scales are generally in the right direction, we would normally expect 0 car to have highest utility (1.78) rather than 1 car (2.91) . This result may be a partial correction for one of the other factors, such as urban location on 0 car households for example.

DISCUSSION AND CONCLUSIONS:

Given the strong growth of car sharing in the Pacific Northwest, as well as across North America, we recommend that further research into car sharing membership be carried out, and this of course also means monitoring the growth in usage of traditional car sharing services, as well as the car ride services, which have been transforming the urban transportation system.

In terms of model results, the combined car-ownership/car-share membership model was successfully estimated. The results for model run 70 made intuitive sense and the model structure was reasonable. The combined model captures a number of key characteristics of the changing role of urban mobility and its impact on car ownership, without requiring a stand-alone model of car-sharing membership to be developed and maintained.

As far as the overall implications emerging from these models, we recommend that auto ownership models be refined to take car sharing membership (and ideally transit pass holding) into account. In many cases, a series of sequential models will be more feasible than estimating and implementing the simultaneous household mobility model outlined in this paper. However, many large and even some mid-sized agencies are moving towards incorporating population synthesis into the model stream, which would make combined models such as the one discussed in this research feasible, since the household characteristics would be available during model implementation.

It is worth noting, of course, that the new mobility paradigm is constantly shifting, and this is a landscape that will be difficult for modellers to keep their footing. Further extensions of this work might involve an explicit focus on one-way car sharing (Car2Go) and the rise of peer-to-peer car sharing. This is a potential tie-in with Big Data, since it is really only with Big Data that one would be able to predict the vehicle availability of one-way car-share vehicles with any granularity.

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