APPENDIX A
OPPORTUNITY ANALYSIS METHODOLOGY

SUMC's opportunity analysis estimates potential demand for carsharing and bikesharing by calculating the disparity between existing resources and new resources that a given market can absorb. To conduct this analysis, SUMC developed a series of models for predicting availability of carsharing and bikesharing within a census block group, based on the key demographic factors in markets where demand and supply are thought to be most balanced. SUMC's researchers used their professional judgement to select areas with the longest and most intensive experience with carsharing and bikesharing in order to set these benchmarks. The resulting "balanced" model was then applied to more than 50 cities across North America, using the difference between predicted and actual levels of carsharing and bikesharing to identify opportunity areas.

This project looked at more than 50 US metropolitan areas and three Canadian cities. The basic carshare and bikeshare models were developed for the US cities and then applied to the Canadian cities with small differences given the difference in availability of data between the two countries. The US and Canadian models are described separately within this appendix.

U.S. MODELS

Data sources

The underlying data for the US models were drawn from products of the US Census Bureau, the Center for Neighborhood Technology's (CNT's) All Transit data repository, and SUMC's carsharing and bikeshare databases.

Response Variables

Using training sets made up of a few of the study cities, SUMC estimated models for each of the shared mobility modes of interest: traditional carsharing vehicle count, one-way carsharing vehicle count, and counts of both bikesharing docks and bikesharing ridership. The outputs for each of these variables correspond to the amount of each shared mode that the model estimates a given area could support. All response variables were calculated by identifying locations of carsharing and bikesharing resources, buffering those locations to show their walkable access shed, identifying the share of each block group covered by those buffers, and summing those shares for each block group. However, the determination of the point locations and the radius of the buffers vary among the shared resources.

For traditional carsharing, the point locations are defined as the vehicles' established parking spots. For one-way carsharing, the point locations are defined as the locations of available vehicles at six different times throughout the day. These data were pulled for a multi-day period from the application programming interface (API) of car2go, the largest one-way carsharing operator in the United States, and then averaged by the number of readings taken. While the data were regularly pulled four times daily over a 12-day period in October 2015, due to problems with the API, the actual total number of readings per city varied between 50 and 54. These numbers were further adjusted based on the regional total reading at 3:00 a.m.—presumably the time of day when the fewest vehicles were in use, and thus uncounted by the API—to account for the share of vehicles in use at any time. For both traditional and one-way carsharing, one-half mile was chosen as the buffer radius to represent the reasonable willingness to walk 10 minutes to access a vehicle.

For bikesharing, the point locations were defined in two ways. The bikeshare stations defined the point locations for one analysis, while bikeshare trips originating from a station defined the point locations for the other analysis. In the latter case, the usage data was adjusted based on the regional total of bikes in the system. In both cases, a buffer radius of one-quarter mile was used, which assumed a somewhat lesser willingness on users' parts to walk to bikesharing locations.

This approach has two advantages. First, these measures can be directly plotted to show a density map of access to carsharing and bikesharing resources. Secondly, these measures can easily be scaled by the size of the block group to calculate the fractional share of the bikesharing or carsharing resource that is "tied" to that block group. These shares can be summed at any geography.

Predictor Variables

The predictor variables represent the factors thought to drive the demand for carsharing and bikesharing. These are all measured at the census block group level.

Type	Variable Name	Description
Population	**Population**	**Total population**
	Population between 18 and 24	Population between ages 18 and 24
	Households	Total count of households
	Households with Kids	Count of households with children less 18 years old
	Households without Kids	Count of households without children
Employment	LAI Local Job Density	A measure of job density within one-half mile of the block group centroid used as part of the HUD Location Affordability Index
	Total Workers	Total employed persons (Census defined age 16 or older)
	Car Commuters	Employed persons who drive to work
Transit	Average Transit Trips Per Week	Average available transit trips per week (Center for Neighborhood Technology All Transit Database)
	Transit Accessible Jobs	Jobs accessible by 30-minute transit ride (Center for Neighborhood Technology All Transit Database)
Urban Form	Intersection Density	Intersections per acre
	Acres	Block group area in acres

Transit Accessibility

To evaluate transit accessibility, this research relies on the Center for Neighborhood Technology's All Transit Database to classify the average number of transit trips per week into three categories. The breakpoints were established based on the distribution of the city type.

Average Transit Trips/Week

Center for Neighborhood Technology All Transit Database. http://alltransit.cnt.org/

City Size	Low	Medium	High
Smaller	<179	179 to 432	>432
Medium	<179	179 to 539	>539
Large	<169	169 to 486	> 486
New York	<369	369 to 844	>844

Training Set Selection

This research identified several training locations for each model. These cities were chosen given their long and engaged commitment to each of the specific shared modes. The market characteristics in these cities were then used to help develop the carshare and bikeshare models for the opportunity analysis.

Model	Training Set Cities
Traditional Carsharing	**Boston-area cities:** Belmont, Boston, Brookline, Cambridge, Malden, Somerville, Watertown **Northern California cities:** Berkeley, Emeryville, Mountain View, Oakland, Palo Alto, Sacramento, San Francisco, San Jose, San Mateo, Sunnyvale, Santa Clara
One-Way Carsharing	Seattle, Washington, DC
Bikesharing: Docks	Chicago, Minneapolis, Washington, DC
Bikesharing: Usage	San Francisco Bay Area, Washington, DC

Model estimates: Traditional Carsharing

The traditional carsharing model was estimated based on data from on a number of cities in the Massachusetts Bay Area and Northern California. The final model, shown below, incorporated density of households without children, local job density, and transit service—each of which is positively associated with traditional carsharing availability. Local job density, as well a number of variables in the proceeding models are transformed from their natural log to adjust for the skewed nature of the data.

Variables	Estimate	SE	t value	p value	Sig.
(Intercept)	-23.58	1.01	-23.34	< 0.001	***
Households Density (Households without Kids)	1.372	0.047	29.05	< 0.001	***
ln(LAI Local Job Density + 1)	9.557	0.536	17.85	< 0.001	***
Average Transit Trips Per Week	0.029	0.002	16.8	< 0.001	***

*Significance codes: < 0.001 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '*
Residual standard error: 4.121 on 910 DF; Adjusted R-squared: 0.51
F-statistic: 313.2 on 3 and 910 DF, p < 0.001

One-Way Carsharing

The one-way carsharing model was based on carsharing resources available at the neighborhood level in Seattle and Washington, DC. The final model, shown below, incorporated the ratio of households with children to all households, population density, and transit access to jobs. One-way car sharing is negatively associated with households with children, but positively associated with population density and transit access to jobs.

Variables	Estimate	SE	t value	p value	Sig.
(Intercept)	-26.273	1.606	-16.364	< 0.001	***
Households with Kids / Households	-3.584	1.088	-3.293	0.001	**
ln(Population / Acres)	2.386	0.185	12.927	< 0.001	***
Transit Accessible Jobs ^0.25	1.091	0.058	18.681	< 0.001	***

*Significance codes: < 0.001 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '*
Residual standard error: 14.52 on 1606 DF; Adjusted R-squared: 0.6
F-statistic: 559.9 on 4 and 1606 DF, p < 0.001

Bikesharing: Docks

The bikesharing docks model is estimated based on bikeshare resources as measured in Minneapolis, Washington, DC, and Chicago. The final model, shown below, incorporated intersection density, population density of young adults, local job density, and transit service—all of which are positively associated with bikesharing availability.

Variables	Estimate	SE	t value	p value	Sig.
(Intercept)	-21.199	1.317	-16.092	< 0.001	***
Intersection Density	0.005	0.002	3.033	0.002	**
Population 18 to 24 / Acres	0.251	0.056	4.522	< 0.001	***
ln(LAI Local Job Density + 1)	13.63	0.378	36.098	< 0.001	***
Average Transit Trips Per Week	0.012	0.002	6.625	< 0.001	***

*Significance codes: < 0.001 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '*
Residual standard error: 14.52 on 1606 DF; Adjusted R-squared: 0.6
F-statistic: 559.9 on 4 and 1606 DF, p < 0.001

Bikesharing: Usage

The bikesharing usage model is estimated on a number of cities in the San Francisco Bay and Washington, DC, areas. The final model, shown below, incorporated intersection density, density of non-car commuters, local job density, and transit service—with bikesharing usage positively associated with each measure. (The maps in the report are based on the bikesharing docks model because it had a higher R-squared value. However, this model is included as a resource in the technical appendix as it offers another perspective on how to evaluate bikeshare programs.)

Variables	Estimate	SE	t value	p value	Sig.
(Intercept)	-37.326	2.277	-16.395	< 0.001	***
Intersection Density	0.006	0.003	2.437	0.015	*
(Total Workers – Car Commuters) / Acres	0.138	0.037	3.703	< 0.001	***
ln (LAI Local Job Density + 1)	12.525	0.61	20.538	< 0.001	***
Average Transit Trips Per Week	0.022	0.003	8.513	< 0.001	***

*Significance codes: < 0.001 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '*
Residual standard error: 20.02 on 1185 DF; Adjusted R-squared: 0.5
F-statistic: 291 on 4 and 1185 DF, p < 0.001

Mapping the Results

The results of the models were mapped for each of the 27 USDN study cities in this report to show where shared mobility opportunities are located. The predicted values represent the estimates for carsharing and bikesharing resources that could be absorbed by the population given the levels of service demonstrated in the training cities. The opportunity areas were classified into three categories based on the distribution for each city size class. This demand is estimated at the census block group level. If a block group were to realize some or all of its modeled potential then it would impact the demand of its neighboring block groups as access extends beyond a census block group's boundary.

Highest Opportunity Areas

These neighborhoods fell within the top 40 percent in terms of their modeled potential to support new, or expand on existing, carshare. Given the ability of different-sized cities to support varied levels of shared mobility, this classification changed for each of the city size classes.

Medium Opportunity Areas

These neighborhoods showed growth for carshare when compared to cities of similar size, but ranked in the lower 60 percent in terms of their modeled capacity to absorb new or expanded carsharing. Similar to the Highest Shared Mobility Areas, the number of carshare vehicles changed based on the city size class. Also included in the Medium Shared Mobility Area is whether the model indicated there was a market for one-way carshare or bikeshare.

First/Last Mile Opportunity Areas

First/last mile opportunities were calculated based on the gross household density of a census block group that was higher than 1.5 households per acre, but where transit availability was less than 0.1 trips per household. These neighborhoods were further evaluated using a rank index optimization score that looked at the walkability and jobs access compared to other block groups of similar density, the idea being that these neighborhoods held the basic qualities needed for shared mobility to be successful but further transit expansion and transit oriented development planning were needed.

CANADIAN MODELS

Data sources

The underlying data for this project were drawn from the products of Statistics Canada and the SUMC carsharing database.

Response Variables

As with the US model, all response variables were calculated by identifying point locations of carsharing and bikesharing resources, buffering those locations, identifying the share of each block group covered by those buffers, and summing those shares for each census tract; however, the determination of the point locations and the radius of the buffers vary among the shared resources.

Predictor Variables

The predictor variables represent the factors thought to drive the demand for carsharing and bikesharing. These are all measured at the Census tract level.

Type	Variable Name	Description
Population	Households	Total households (2011 Census)
Transit	Transit Index	Average number routes available at census tract level (see Transit Availability, below)
Urban Form	Intersection Density	Intersections per acre
	Acres	Number of Census tract acres

Transit Availability

Due to data limitations (the All Transit Database is based only on U.S. transit agency service data), an alternate transit availability measure was created for the two Canadian cities in the study. The transit measure is based on the bus and rail stop data. A quarter mile buffer is created for each bus stop and half mile buffer is created for rail stop and the fractional accessibility at the census tract level is then summarized and then divided by the census tract area. The result is a transit availability measure that looks at the average number of routes that are accessible at the census tract level.[2]

Transit Availability			
	Low	Medium	High
Victoria	< 3	3 to 6	>6
Toronto	<13	13 to 26	>26

Training Set Selection

This research identified training locations for each model.

Model	Training Set Cities
Traditional Carsharing	Vancouver
One-Way Carsharing	Vancouver
Bikesharing	Toronto

Model estimates

Traditional Carsharing

The traditional carsharing model was estimated based on Vancouver's data. The final model, shown below, incorporated the density of households, the intersection density, and the transit index, with traditional carsharing availability being positively associated with each measure.

Variables	Estimate	SE	t value	p value	Sig.
(Intercept)	-7.635	0.699	-10.924	< 0.001	***
(Households / Acres) ^0.5	7.464	0.894	8.345	< 0.001	***
Intersection Density ^0.5	9.159	1.462	6.264	< 0.001	***
Transit Index	0.617	0.110	5.599	< 0.001	***

Significance codes: < 0.001 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '
Residual standard error: 8.13 on 453 DF; Adjusted R-squared: 0.5036
F-statistic: 155.2 on 3 and 453 DF, p < 0.001

[2] Transit measures adapted from a method outlined in these two studies: "Estimating Transportation Costs by Characteristics of Neighborhood and Household". Center for Neighborhood Technology. Transportation Research

One-Way Carsharing

The one-way carsharing model was estimated on Vancouver's data. The final model, shown below, incorporated the density of households, intersection density, and the transit index, each of which is positively associated with one-way carsharing.

Variables	Estimate	SE	t value	p value	Sig.
(Intercept)	-4.118	0.869	-4.737	< 0.001	***
(Households / Acres) ^0.5	2.850	0.855	3.334	0.001	**
Intersection Density ^0.5	5.402	1.408	3.837	< 0.001	***
Transit Index	0.892	0.102	8.721	< 0.001	***

Significance codes: < 0.001 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '
Residual standard error: 5.715 on 186 DF; Adjusted R-squared: 0.6113
F-statistic: 100.1 on 3 and 186 DF, p < 0.001

Comparing the one-way carsharing availability predicted by this model with the actual availability measured yields the following graph with the red line demonstrating perfect prediction.

Bike Sharing: Docks

The bikesharing (docks) model is estimated based on Toronto. The final model, shown below, incorporated household density and transit service as well as the interaction of those two variables.

Variables	Estimate	SE	t value	p value	Sig.
(Intercept)	-43.442	16.337	-2.659	0.011	*
(Households / Acres) ^0.5	30.970	12.265	2.525	0.015	*
Transit Index	3.396	0.729	4.656	< 0.001	***
(Households / Acres) ^0.5 * Transit Index	-1.230	0.552	-2.227	0.031	*

Significance codes: < 0.001 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '
Residual standard error: 19.49 on 49 DF; Adjusted R-squared: 0.4151
F-statistic: 13.3 on 3 and 49 DF, p < 0.001

Application

The predicted values represent the estimates for carsharing and bikesharing resources that could be absorbed by the population given the levels of service demonstrated in the training cities. Negative predictions are censored at zero.

The actual values are subtracted from the predicted values to identify the difference and therefore growth potential for each census block group. Once again, negative differences (meaning that the current resources exceeds the predicted) are censored at zero. This censoring assumes that the vagaries of local conditions justify the current supply and that that supply should not be diminished.

Finally, the area values are converted into absolute values by calculating the fractional portion of each resource linked to the specific block group. These fractional values are summed to calculate the estimates for increased carshare and bikeshare resources at the regional level.

Highest Opportunity Areas

The neighborhoods that fell within the top 40 percent in terms of their modeled potential to support new or expand on existing carshare. Given the ability of different size cities to support varied levels of shared mobility, and that the model is only available for Victoria and Toronto, the classification was unique for each city.

Medium Opportunity Areas

These neighborhoods showed growth for carshare, but ranked in the bottom 60 percent in terms of their modeled capacity to absorb new or expanded carshare. Similar to the Highest Shared Mobility Areas, the number of carshare and bikeshare resources was based on the modeled results for Victoria and Toronto separately. Also included in the Medium shared mobility area is whether the model indicated there was a market for one-way carshare and bikeshare.

First/Last Mile Opportunity Areas

Due to data limitations, first/last mile opportunities were not considered in this analysis.

Opportunity Characteristics by City Size Class

The following table contains a summary of demographic information underpinning SUMC's Shared Mobility opportunity analysis tool. Shown here are communities with high, medium, and first/last mile opportunities to scale up shared mobility, categorized by city size class. These data provide a framework that cities can use to establish benchmarks for shared mobility and assess potential impacts on auto ownership. In general, the areas with the greatest shared mobility opportunity are those with the highest public transit use and availability, lowest vehicle ownership rates, and greatest walkability as measured by average block size.

Shared Mobility Opportunity Characteristics								
City Size Class	Shared Mobility Opportunity	Households per Acre (Gross Density)	% Drove Alone to Work	% Carpooled to Work	% Public Transit to Work	Average Vehicles/ Household	Average Transit Trips/ Week	Average Block Size
Smaller	High	5.8	48%	5%	10%	1.2	432	6.9
Smaller	Medium	3.1	61%	9%	7%	1.5	272	9.3
Smaller	First/Last Mile	2.4	76%	11%	2%	1.7	102	10.4
Medium	High	8.5	46%	7%	24%	1.0	644	5.1
Medium	Medium	3.5	62%	10%	15%	1.3	395	7.2
Medium	First/Last Mile	2.9	80%	9%	3%	1.6	81	12.8
Large	High	10.1	54%	9%	22%	1.0	652	4.0
Large	Medium	3.7	69%	11%	10%	1.5	386	7.4
Large	First/Last Mile	2.9	80%	10%	2%	1.8	84	13.3
New York City	High	36.8	15%	4%	61%	0.4	958	4.3
New York City	Medium	7.5	37%	7%	46%	0.9	718	5.4
New York City	First/Last Mile	5.5	60%	12%	23%	1.4	46	4.6

American Community Survey 2013 data summarized from the Census block group level. Average transit trips/week compiled from the Center for Neighborhood Technology's All Transit Database.