March 19, 19

To: Ryan Lanyon, Shagithya Deivendran, Fahad Khan, City of Toronto Transportation Services Division
From: Matthias Sweet, Niranjan Rajevan, Ryerson University School of Urban & Regional Planning, TransForm Lab
Subject: Trip-level estimates of behavioral sensitivity to potential automated vehicle attributes

This memorandum explores Greater Toronto and Hamilton Area residents' estimated interest in driverless on-demand ride hailing (robo-taxis) or driverless public transit services. This memorandum further explores respondent sensitivity to on-demand ride hailing services, should vehicles be shared with other trip takers. This study uses a 2018 consumer survey data to estimate behavioral sensitivity of Greater Toronto and Hamilton Area residents to automated attributes of services which may be delivered for trip-level travel decisions. This memorandum focuses exclusively on surveyed residents who had at least one car in their household and who have a driver's license.

Study Purpose

This study aims to identify the conditions under which consumers are sensitive to specific trip-level attributes of travel alternatives which are hypothesized to be components of a possible future involving Level 5 automated vehicles (vehicles which can auto-navigate with no role for humans to complete safety-critical functions).

Study findings explore:

1) Under what conditions are transportation system users sensitive to whether or not on-demand, ride-hailing (like Uber or Lyft) is provided by a driver (as currently) or by a driverless vehicle (a robo-taxi)?

2) Under what conditions are transportation system users sensitive to whether or not public transit is provided by a driver (as currently) or by a driverless shuttle?

3) Under what conditions are transportation system users sensitive to whether or not on-demand, ride-hailing is provided when the trip is shared with another passenger relative to when such a service is provided to only one trip taker?

The rationales for answering these questions are three-fold. First, one potential ownership model for automated vehicles is that transportation network corporations (TNCs), such as Uber or Lyft, would use driverless vehicles instead of conventional vehicles driven by humans. While this may significantly reduce the cost of labour related to on-demand ride-hailing, the consumer price would also depend on the upfront capital costs of purchasing Level 5 automated vehicles. Insofar, that trips can be provided at slightly lower costs than currently, understanding the potential market for such a product also depends on whether consumers are likely to be significantly less interested in on-demand ride hailing when it is provided by a driverless car. This research aims to answer that question.

Second, part of an increasingly automated transportation system might include driverless transit vehicles (e.g. shuttle buses). As such, it is important to understand the balance of whether transit costs (when provided by driverless transit vehicles) are likely to decrease (not the focus of this memorandum) or whether the quality of transit services is perceived as significantly less desirable when provided by a driverless vehicle (one topic of this memorandum). Although it is unlikely that automated transit vehicles would lead to immediate reductions in the cost of delivering services (e.g. a service chaperone may still be used in a driverless bus), unit cost reductions of delivering transit services could be reduced over the long-term.

Third, on-demand ride hailing which is shared with other passengers appears to be one potential key ingredient improving the emissions reductions derived from on-demand ride-sharing. By serving more passengers with fewer vehicles, there may be greater opportunities to reduce greenhouse gases through shared on-demand ride hailing. As such, understanding the conditions under which consumers are willing to share a transit vehicle with other transportation system users is important.

Stated Preference Question Description

This study provides insight into each of these three questions using a conjoint analysis. Four stated preference choice experiments were administered to each survey participant[1] (N=3,200). This memorandum focuses only on respondents who have a driver's license and have at least one vehicle in their household to which they have access. Choice experiments for *home-based-work (N=1,475 participants)*, *home-based restaurant/eatery (N=2,117 participants)*, and *home-based shopping* (N=2,115 participants) appeared to respondents as follows:

Imagine you are taking a trip to a restaurant or eatery and your are departing from your home.
What option would you choose?

	Option Characteristics	Drive	Cycle	On-demand car	Transit + on-demand car	Transit + walk
Travel time		15 min.	20 min.	30 min.	20 min.	20 min.
Cost		$8 parking	None.	$12 one-way	$4 one-way	$5 one-way
Driverless shuttle?	?				n/a	Transit vehicle uses driverless technology (there is no driver).
Additional Passengers?	+ ?			n/a	n/a	
Driver? or Driverless car?	?			On-demand car is driven by a driver.	On-demand car is driven by a driver.	
	Select→	O	O	O	O	O

Figure 1. Sample Stated Preference Choice Experiment

Travel times provided to participants for each alternative ranged from 15 minutes to 60 minutes and the cost of a trip ranged from free to $12. Driverless shuttles were either identified as using "driverless technology (there is no driver)" or not ("n/a"), additional passengers on on-demand cars were identified as either, "on-demand

[1] *All survey participants were equally likely to be asked questions related to shopping or restaurant/eatery trips, but cases in which a survey participant was asked a survey question related to work/school trips and that individual was not employed and was not a post-secondary student, that question was omitted. This does not affect the results of models presented here.*

car shared with another customer," or "on-demand car is driven by a driver." Additional passengers in on-demand cars are identified as either, "on-demand service shared with another customer," or "n/a."

Survey respondents were invited to respond to stated preference choice experiments based on the characteristics of each alternative. As such, the sensitivity of residents to different service levels could be estimated by understanding respondents' stated choices on the basis the relative characteristics of the attributes of different alternative options.

Model description and rationale

Multinomial logistic regression models are estimated using the data collected about survey respondents' individual characteristics (e.g. age, employment status, sex, educational attainment, etc.), household characteristics (household size, presence of children under 15, household income, etc.), residential neighborhood characteristics (population density, job density, etc.), available mobility tools (access to a bicycle, household vehicle ownership, etc.), and the characteristics of each of the stated choice experiment alternatives. Several land use variables are tested but all are omitted in final models due to insignificance.

The models take on the following functional form:

$$(1)\quad P(Y_i = R) = \frac{e^{\beta_{kr} X_{ik}}}{\sum_{j \in j_r} e^{\beta_{kr} X_{jk}}} = \hat{Y}_{ir} \ ,$$

where Y_i represents the individual i; R represents the possible modes (drive, bicycle, on-demand ride hailing, public transit plus on-demand ride hailing, or public transit plus walking); β_{kr} represent coefficients to be estimated for each mode response (r) and independent variable (k); and X_{ik} represents the value of the dependent variable for individual i and variable k; $j \in j_r$ represents option j within choice set j_r and X_{jk} represents the independent variable values for variable k and choice alternative j. Driving represents the reference category to which all other mode options are compared.

The links between three specific variables and prospective travel choices are the focus of this initiative:

- whether an on-demand ride-hailing alternative generates less utility should it be provided by a driverless vehicle (relative to a vehicle with a driver),
- whether or not sharing an on-demand ride-hailing vehicle with other passengers generates less utility (relative to not sharing a vehicle), and
- whether or not a public transit service is provided using driverless technology (relative to with a driver) generates less utility for passengers.

Results

Model results are estimated when centering the data around the mean values of each independent variable within the dataset. As such, coefficient estimates can be interpreted as behavioral sensitivity for an individual with the "mean" underlying characteristics.

Driverless on-demand ride hailing

When provided by a driverless vehicle, survey respondents were more likely to adopt on-demand ride hailing for home-based-work trips only (coefficient of 0.36 – see Table 1). This indicates that the relative risk of using driverless on-demand ride-hailing compared to conventional (with a driver) on-demand ride-hailing would increase by 43% (0.43 = e^0.36 - 1)[2]. The estimated effect of on-demand ride hailing being provided by a driverless car was negative (but statistically insignificant) for restaurant/eatery (see Table 2) and shopping (see Table 3) trips and was likewise statistically insignificant when used in connection with public transit. These findings suggest that, for most trips, driverless on-demand ride hailing is expected to be similarly attractive to consumers as current on-demand ride-hailing provided with drivers (e.g. Uber or Lyft). Only for home-based-work trips did on-demand ride hailing without a driver become more attractive than with a driver (43% more likely). As taxi or on-demand ride-hailing represent very low existing market shares (especially for commuting), this represents a niche travel market becoming relatively more attractive. These findings are independent of the time or financial cost of a trip. As such for driverless on-demand ride hailing to become a larger market share than current on-demand ride hailing (Uber and Lyft), this would depend on the likelihood and magnitude of cost savings related to reducing the need to pay drivers' wages. As such, for the "average" survey participant taking a home-based-work trip, a driverless on-demand ride hailing trip (relative to one with a driver) can be transformed into approximately $2.25 of utility ($2.23 = +0.36 estimated effect of driverless on-demand ride hailing / +0.16 estimated effect of one dollar decrease in price).

On-demand ride hailing shared with other passengers

Results suggest that when other passengers share on-demand ride hailing with other individuals, the probability of using on-demand ride hailing only (statistically significantly) decreases for home-based restaurant/eatery trips. The coefficient estimate is only significant for the on-demand ride hailing mode and not the transit plus on-demand ride hailing mode. When converting the estimated effect of shared on-demand ride-hailing at mean values for all variables, this represents a $2.50 reduction in utility per trip ($2.50 = -0.33 estimated effect of on-demand ride hailing *shared with another passenger* / -0.13 estimated effect of one dollar increase in price). These effects are only significant for one of the three trip types and are estimated independently of the effects of travel times and costs. As such, one would expect the outlook for shared on-demand ride hailing to become a viable market to depend on the economies of scale which would be expected to affect service levels, travel times, and travel costs.

[2] Relative risk represents the change in the probability of choosing the on-demand ride hailing option with a driverless vehicle compared to the probability of choosing the on-demand ride hailing option with a driver (as provided by Uber and Lyft) – holding all other price and service attributes constant.

Driverless Transit

Finally, results indicate that consumers were only less likely to use driverless transit (as opposed to conventional transit) when provided in conjunction with on-demand ride hailing for restaurant/eatery trips. The estimated effect of driverless transit (as opposed to conventional transit) was statistically insignificant for all other trip types and for all trips involving transit and walking. As such, results suggest that should transit be provided by a driverless vehicle, this service would be viewed as a disutility only for specific trips: those connecting with on-demand ride hailing modes for home-based restaurant/eatery trips. The expected effect is estimated to be equivalent to a net disutility equivalent to a $3.77 penalty (-0.49 utility per driverless transit / -0.13 utility per dollar=$3.77). As such, the balance of whether shifting transit towards driverless services would increase or decrease ridership appears to hinge (at least for most transit trips) on the potential changes in service qualities or service prices from shifting to driverless vehicles.

Conclusions

Overall, results suggest that the outlook for automated on-demand ride hailing, shared ride hailing, or driverless transit to dramatically change existing travel market shares should be viewed cautiously and is likely to be shaped (in large part) by the potential cost savings from integrating these technologies into transportation service provision. Potential cost savings and their implications (e.g. related to labour) need to be further understood. Results from this study provide no statistically significant evidence of a disutility related to driverless on-demand ride hailing (as opposed to with a driver) – rather for home-based work, driverless vehicles are viewed as more desirable. Results indicate that sharing on-demand ride hailing with other passengers generates a disutility for restaurant/eatery trips but is statistically indistinguishable from zero for other trips. Finally results indicate that the estimated effect of transit services being provided by a driverless vehicle (as opposed to a vehicle with a driver) is only a statistically significant disutility for transit trips connecting with on-demand ride hailing (but not for transit trips linked with walking egress). Overall, results suggest that without significant reductions in monetary prices while retaining service quality, driverless vehicles or vehicle sharing are unlikely to significantly change transit market shares (e.g. as a complement through access/egress connections or) or on-demand ride hailing market shares.

Broader implications of this research relate to the outlook for driverless vehicles to become a significant market share based on an on-demand, for-hire ownership model. Findings lead one to question whether driverless on-demand ridesharing is likely to become a more meaningful complement to public transit or to become a significant market share for tour-level decisions. Results from this study imply that while consumers appear to respond to driverless on-demand ride hailing and shared on-demand ride hailing, without significant changes in consumers' fundamental motivations or without changes to prices (via the cost of delivering services), on-demand ride hailing is unlikely to become a more significant mode share.

In terms of public transit service provision using driverless shuttles, results from this study suggest that consumers are neither more nor less likely to use such services than when transit is provided with a driver (as currently). In short, the viability and desirability of driverless transit depends more prominently on a) the immediate results of driverless technologies and the secondary (possible) impacts on the relative roles of humans (and their wages) in providing driverless transit. Should providing services become significantly more cost effective, it is further unclear whether/how services may be expanded and/or funds may be used for other public purposes.

Table 1. Multinomial logistic regression model results for home-based-work trips (employed commuters or post-secondary students with >0 cars in household, access to a car, and a driver's license)

	Drive (reference)	Bicycle	On-demand ride-hailing	Transit + On-demand Ride Hailing	Transit + Walking
Intercept	--	-2.25***	-1.08***	-1.66***	-1.26***
Price ($)	-0.16***				
Other passenger in on-demand ride hailing (binary)			-0.23	-0.06	
Driverless transit (binary)				-0.1	-0.1
Driverless on-demand ride hailing (binary)			0.36*	-0.1	
Age (years	--	-0.01	0	-0.01	0.01*
Sex (Male)	--	0.23	0.2	0.27	0.3*
Employment Status: Retired, Not Employed, Other (binary)	--	--	--	--	--
Non-student (binary)	--	1.02***	0.8**	1.11***	1.03***
Part-time student (binary)	--	0.57*	0.04	0.18	1.03***
Educational attainment: bachelor's, graduate, or professional degree (binary)	--	0.22	0.52***	0.36.	0.72***
Household size	--	-0.04	-0.07	0.02	0.04
Household income < $60,000 (binary)	--	0.42*	0	-0.53*	0.06
Household income: unknown/no response (binary)	--	-0.4	-0.18	-0.01	0.06
Google car knowledge= yes (binary)	--	0.5**	0.56**	0.16	0.61***
Bicycle access = yes (binary)	--	0.92***	0.1	-0.19	0
Household vehicle count	--	-0.41***	-0.27*	-0.57***	-0.62***
Car share membership = yes (binary)	--	-0.11	0.33	0.49	-0.79**
Travel Time (minutes)	-0.03***	-0.04***	-0.04***	-0.06***	-0.03***
N=1425 unique individuals; 2355 choice experiments					
McFadden R-Squared: 0.109					
Log-Likelihood: -2581.7					

Note: Significance indicated at 0.10 (.), 0.05 (*), 0.01 (**), and 0.001 (***)-levels

Table 2. Multinomial logistic regression model results for home-based-restaurant/eatery Trips (individuals with >0 cars in household, with a driver's license, and access to a car)

	Drive (reference)	Bicycle	On-demand ride-hailing	Transit + On-demand Ride Hailing	Transit + Walking
Intercept	--	-2.6***	-1.18***	-2.12***	-1.75***
Price ($)	-0.13***				
Other passenger in on-demand ride hailing (binary)	--	--	-0.32*	-0.22	--
Driverless transit (binary)	--	--	--	0.13*	0.13
Driverless on-demand ride hailing (binary)	--	--	-0.13	-0.13	--
Age (years	--	-0.02***	0.01	0.01	0.01*
Sex (Male)	--	0.24.	0.15	0	0.32*
Employment Status: Retired, Not Employed, Other (binary)	--	-0.31.	-0.36*	-0.55*	-0.38*
Non-student (binary)	--	0.41	0.64*	0.65	0.63*
Part-time student (binary)	--	0.64*	0.02	0.63.	1.03***
Educational attainment: bachelor's, graduate, or professional degree (binary)	--	0	0.04	-0.03	0.4**
Household size	--	-0.01	0.03	-0.08	0
Household income < $60,000 (binary)	--	0.45**	-0.16	-0.67*	-0.1
Household income: unknown/no response (binary)	--	0.27	-0.22	-0.36	-0.3
Google car knowledge= yes (binary)	--	-0.2	-0.08	-0.21	-0.05
Bicycle access = yes (binary)	--	0.71***	0.05	0.09	0.28*
Household vehicle count	--	-0.41***	-0.4***	-0.13	-0.76***
Car share membership = yes (binary)	--	0.84***	0.85***	1.32***	0.12
Travel Time (minutes)	-0.03***	-0.03***	-0.03***	-0.03***	-0.03***
N=2,117 unique individuals; 3528 choice experiments					
McFadden R-Squared: 0.089					
Log-Likelihood: -3444.9					

Note: Significance indicated at 0.10 (.), 0.05 (*), 0.01 (**), and 0.001 (***)-levels

Table 3. Multinomial logistic regression model results for home-based-shopping trips (individuals with >0 cars in household, with a driver's license, and access to a car)

	Drive (reference)	Bicycle	On-demand ride-hailing	Transit + On-demand Ride Hailing	Transit + Walking
Intercept	--	-2.77***	-1.61***	-2.56***	-1.88***
Price ($)	-0.15***				
Other passenger in on-demand ride hailing (binary)	--	--	-0.17	0.26	--
Driverless transit (binary)	--	--	--	0.09	0.09
Driverless on-demand ride hailing (binary)	--	--	0.08	0.08	--
Age (years	--	-0.02**	-0.02**	0.01	0
Sex (Male)	--	0.64***	0.26*	0.14	0.13
Employment Status: Retired, Not Employed, Other (binary)	--	-0.62**	0.15	-1.01***	-0.34*
Non-student (binary)	--	0.64*	0.18	0.28	0.18
Part-time student (binary)	--	0.5.	0.2	0.17	0.85***
Educational attainment: bachelor's, graduate, or professional degree (binary)	--	-0.07	0.23.	0.1	0.26.
Household size	--	-0.21***	-0.04	-0.02	-0.04
Household income < $60,000 (binary)	--	0.39*	-0.08	0.36	0.01
Household income: unknown/no response (binary)	--	0.38.	-0.69**	-0.08	0.16
Google car knowledge= yes (binary)	--	0.19	0.49**	0	0.2
Bicycle access = yes (binary)	--	0.79***	-0.25.	0.27	0.1
Household vehicle count	--	-0.24*	-0.2*	-0.45**	-0.69***
Car share membership = yes (binary)	--	0.6*	0.51*	1.61***	0.16
Travel Time	-0.03***	-0.03***	-0.05***	-0.04***	-0.03***
N= 2,115 unique individuals; 3504 choice experiments					
McFadden R-Squared: 0.109					
Log-Likelihood: -3125.9					