Mapping Cycling Potential in Toronto

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Abstract

Many municipalities are investing in cycling infrastructure; these efforts increase safety and comfort, and typically occur in central neighbourhoods as they have a higher proportion of cyclists. However, targeting cycling investments in neighbourhoods with a strong latent demand for cycling, regardless of their current cycling mode share, may also increase cycling adoption. Accordingly, the aim of this paper is to identify areas that present the highest potential for cycling uptake. To this end, we use data from the most recent 2016 Transportation Tomorrow Survey in Toronto and conduct a generalized linear model to uncover the sociodemographic, behavioural, and land use characteristics that influence cycling mode share. We identify areas with a lower cycling mode share than predicted by our model and argue that these present a higher potential for cycling. Governments interested in increasing cycling mode share should consider expanding their efforts and investments beyond central neighbourhoods, as those with a latent demand for cycling may also yield positive results for cycling mode share.

Key words: Cycling mode share; travel demand; Cycling infrastructure; latent demand, cycling potential

1 Introduction

Ensuring cycling interventions are directed at neighbourhoods that will receive strong benefits is of the utmost importance given the limited fiscal capacity of government. Safety and comfort of existing cyclists as well as increasing the number of trips carried out by bicycle can compete for priority when planning for active transportation. Current practice generally favours cycling investment in dense urban areas where the cycling mode share is already relatively high, supporting the comfort and safety of those travellers. This reflects the prevailing ridership – coverage trade-off faced by numerous transit agencies when determine how to allocate their resources (Walker, 2012). However, there has also been increased interest in investing in lower density suburban areas, where there are fewer other transportation options. These areas usually display low cycling mode shares to begin with but have been shown, given the right investments, to possess considerable cycling uptake potential (Kearns et al., 2019). The success of such interventions and investments in low-density areas suggests that governments interested in increasing their city's cycling mode share should consider supplementing their existing priorities for cycling infrastructure and programs with additional targeted investments in areas which present a high potential for cycling uptake despite low current cycling rates. The aim of this research is to examine the factors associated with cycling in order to identify such areas with a high potential for cycling. Increasing the number of trips undertaken by bicycle includes three components: new cyclists; current cyclists carrying out more trips by bicycle and; cyclists who might otherwise abandon cycling instead continuing to travel by bicycle. This paper focuses on increasing cycling rates by adding new cyclists.

In the following section we review the literature on cycling mode share and identify factors associated with cycling uptake. We describe our data and present our estimation strategy in the third section. We then use a generalized linear model (GLM) to identify factors associated with cycling uptake and to uncover areas in Toronto with a high potential for cycling. This is accompanied by a case study analysis and a discussion focusing primarily on the implications of these results for future cycling investments. A brief summary and concluding remarks comprise the final sections of this paper.

2 Literature review

A number of factors have been shown to influence cycling rates: most prominently, the built form, the presence of cycling infrastructure, user and trip attributes, environmental factors, and existing social norms (Buehler and Pucher, 2012; Gatersleben and Uzzell, 2007; Heinen et al., 2010). In all cases, we are referring to manually operated bicycles, not those with e-assists. Many of the papers cited refer to the North American context, yet those by De Geus, 2007; De Geus et al., 2008; Wardman et al., 2007; Kandt et al., 2015) are based on European data. The literature relating to each of these broader parameters is described below.

2.1 Built form

Cycling is more likely to occur in dense urban areas, which typically comprise shorter blocks, grid like street patterns, and a mix of land uses (Cervero et al., 2009; Schneider and Stefanich, 2014). However, by themselves aspects of the built form such as density, diversity, and design are shown to only have modest effects on mode choice (Cervero and Kockelman, 1997).

2.2 Cycling infrastructure

There is a clear relationship between cycling mode share and the presence of cycling infrastructure (Stinson and Bhat, 2005; Buehler and Pucher, 2012). While the effect of cycling infrastructure on objective safety may remain unclear, their effect on subjective safety (i.e. the stated safety experience of users) is largely undisputed, and adding cycling infrastructure will increase cycling mode share by encouraging those who currently avoid this mode due to safety concerns (Heinen et al., 2010). Proximity to these infrastructures is also shown to matter (Carver et al., 2015; Cervero et al., 2009); according to Dill and Voros (2007), people are more likely to cycle if cycling infrastructures were available, easy to reach, and well connected to useful destinations.

2.3 User and trip attributes

Socioeconomic characteristics are also shown to affect cycling uptake. Cycling remains a physically demanding task and seniors are often found to cycle less due to their decreasing strength (Pucher et al., 1999; Dill and Voros, 2007). Age, however, has also been shown not to impact cycling mode share in a European context (De Geus, 2007; Wardman et al., 2007), and while evidence exists to suggest that cycling levels may decline with age, it is unclear whether this relationship is consistent worldwide. The availability of alternative travel modes influences users' travel behaviours. Car ownership and free car parking at work reduce the likelihood for cycling (Cervero, 1996; Dill and Voros, 2007; Buehler, 2012), whereas holding a transit pass may marginally increase the odds of cycling (Singleton and Clifton, 2014). Other socioeconomic attributes such as income, gender, and employment status have also been shown to vary depending on the geographic context. For example, men have been found to cycle more than women in the United States (Dill and Voros, 2007), but this has not always been found to be the case in Europe (De Geus, 2007; Wardman et al., 2007; Pucher and Buehler, 2007). Most research also identifies distance as a significant predictor for cycling, and finds the propensity for cycling to decrease as trip distances increase (Pucher and Buehler, 2007; Cervero, 1996).

2.4 Environmental factors

Overall, Pucher and Buehler (2007) believe the impact of climate and weather to be negligible in comparison to other factors and base this assertion on the fact that Canadians cycle more than Americans, despite having longer and colder winters. Topography, however, is shown to matter as the presence of steep terrain reduces the likelihood of cycling (Schneider and Stefanich, 2014; Cervero et al., 2009).

2.5 Existing social norms and role models

Social pressures are also shown to impact cycling mode share. Cycling uptake is infectious and as cycling becomes more popular in a particular area, others will mirror this behaviour and begin to cycle as well (De Geus et al., 2008; Wang et al., 2015).

Residential location is also closely tied to how social norms are interpreted and displayed. Those with “traditional car-oriented” aspirations have attitudes that are consistent with the options available in low density suburbs, coupled with the constraint that a car-dependent environment provides (Kandt et al., 2015). Cycling interventions must address this group’s aspirations appropriately.

A review of the literature makes clear that there are numerous factors that influence cycling and while their effect may be ambiguous at times, it is crucial to include as many as possible in our analysis to determine which areas have the highest potential for cycling adoption.

3 Methodology

This section details the data sources and estimation approach utilized to identify potential factors related to cycling mode share.

3.1 Data

We use the 2016 Transportation Tomorrow Survey (TTS) administered by the Transportation Information Steering Committee and provided through the University of Toronto’s Data Management Group (Data Management Group, 2017). The survey is conducted in the Greater Toronto and Hamilton Area and the Greater Golden Horseshoe, online and by phone. Only the survey data for City of Toronto was used in this analysis. The sampling rate for Toronto was 5%, and the survey results were expanded to match census counts.

Toronto is subdivided into 625 Traffic Analysis Zones (TAZs), on average 1 km² and approximately 5000 people. Of these 625 TAZs, 70 (11.2%) have no survey data because they have few or no residents (due to being in industrial areas, airports, or greenspace). A further 28 TAZs (4.5%) have fewer than 30 reported trips (before expansion), and were therefore excluded from the analysis to avoid statistical inaccuracies. Data from the remaining 527 TAZs was used as the basis for all of the transportation and demographic variables.

A number of auxiliary datasets were used to determine variables relating to the physical environment. A dataset of street centrelines for Toronto’s public right of ways was used to generate metrics on different types of bike-accessible infrastructure. A triangular irregular network of elevation data for Toronto was used to calculate topographies for each TAZ. We then summed the absolute elevation difference between the start and end of each road segment and divided it by the total length of roads for each TAZ, to obtain an absolute average grade. These datasets are accessible on the City of Toronto’s Open

Data Catalogue. Lastly, a dataset of bus stop locations published by the Toronto Transit Commission was used to calculate transit access.

All analyses were performed at the TAZ level. Variables that were already at the TAZ level (e.g. walking mode share, transit pass ownership) were simply kept as percentages. Categorical and continuous variables (e.g. employment status and trip distance) were converted to binary variables and calculated as a percentage of the total.

A list of factors that were expected to correlate with cycling mode share was established based upon the literature review as well as previous work mapping cycling potential in the Greater Toronto Area (Ledsham et al., 2014). These were broken down into three categories: transportation behaviour, demographics, and physical attributes.

Access to private vehicles as an explanatory variable was measured using the average number of vehicles per adult household member. The decision to only include adults rather than all household members is well supported in the literature (Tal and Handy, 2010; Sentenac-Chemin, 2012) and is a more accurate determinant of mode share decisions. The trip distance variables use Manhattan distance rather than actual network distance observed, but given Toronto's fairly uniform rectilinear street grid (Badia et al., 2016), these two metrics should be highly correlated. We referred to the City's cycling infrastructure definitions to calculate the density of painted bike lanes, cycle tracks, and multi-use paths. The City of Toronto also lists some streets as "recommended cycling routes" or routes that have signs to indicate their suitability for cycling. They are generally on narrower streets that have lower volumes of motorized vehicles, but have no physical or legal differences that improve their cyclability. Bikeways (particularly separated or protected bikeways) were expected to be strongly correlated with cycling mode share. In order to ensure that the effect of bikeways on a TAZ was consistent for TAZs of different sizes and sufficiently diffuse for small TAZs, the density of bikeways was calculated within a 1km buffer around the TAZ's centroid rather than simply within the TAZ's boundary.

Table 1: ***Factors Analyzed for Correlation with Cycling Mode Share***

Type	Factor	Variable	Hypothesized Relationship with Cycling Mode Share
Transportation	Access to private vehicles	Average number of vehicles per adult household member	Negative
	Trip distance	% of trips < 4 km	Positive
		% of trips 4-8 km	Positive
	Trip frequency	Average daily trips per person	Positive
	Availability of free parking at work	% of individuals with no access to free parking at work	Positive
	Transit pass ownership	% of individuals with a transit pass	Positive
Demographics	Age	% of individuals younger than 18	Negative
		% of individuals 65 and older	Negative
	Employment status	% of individuals working full-time	Positive
		% of individuals working part-time	Positive
Physical	Population density	Population density (people/m²)	Positive
	Dwelling type	% of individuals living in a low-rise house	Negative
	Density of transit stops	Bus stop density (stops/km²)	Positive
	Cycling infrastructure (3 sub-categories)	A) Linear density of painted bike lanes and cycle tracks	Positive
		B) Linear density of paved multi-use paths	Positive
		C) Linear density of recommended/ signed on-street cycling routes	Positive
	Average grade of roadways	Absolute average grade of cyclable roads	Negative

3.2 Estimation Strategy

As the proportion of cyclists in a given TAZ may be considered a fractional response variable, we use a GLM rather than ordinary least square to model and explain the variance in cycling rates. The GLM approach is shown to better account for the nonlinearity inherent to percentage-based dependent variables (Papke and Wooldrige, 1996), and to have a similar functional form as the binomial logit mode, which allows for proportional responses that range from 0 to 1.The analysis was conducted on Stata 13, as the GLM command in this version has recently updated to deal with this form of

response variable. For all models, we chose to apply weights corresponding to the overall number of trips per TAZ. This is to ensure that high cycling mode shares based on smaller samples have less of an effect on the coefficient estimates than those based on larger sample sizes.

We begin by conducting two models in our analysis, a full model containing all independent variables, and a reduced model resulting from a backward stepwise selection process. A third model is later calibrated to account for spatial patterns. Using the Akaike and Baysian Information Criterions (AIC and BIC) we determine that the reduced model is a more efficient predictor of cycling mode share than the full model, as it excludes irrelevant variables. The predictive power of both models is approximately 61%, which we establish using the squared correlation coefficients between the observed and predicted cycling mode-share percentages.

Additionally, a series of statistical checks are performed to ensure the assumptions of the modelling approach are not violated. These included testing for multicolinearity, homoscedasticity, and spatial autocorrelation. While verifying for spatial autocorrelation, we find the Moran's I for the dependent variable and for the residuals of the reduced GLM model to be positive and significant, thus suggesting the presence of spatial patterns in our model. To correct this, we included a spatially lagged term, which is a specification of cycling mode share in adjacent TAZs, and we find it to be positive and significant.[1] This indicates that a TAZ's cycling mode share covaries with that of neighbouring TAZs. The addition of a spatially lagged term does not entirely correct for spatial autocorrelation, but rather accounts for a portion of it, and reduces the Moran's I for the residuals. The Moran's I remains significant however, which signals a slight positive spatial autocorrelation in our model even once controlling for spatial patterns. Fortunately, the sign and significance of other variables does not change with the addition of a spatially lagged term, which strongly supports the relationships we observe. We focus our analysis primarily on the effect-size using exponentiated regression coefficients to generate odd ratios, but also use estimated partial derivatives to establish marginal effects. The following section of this paper interprets the findings based on the spatial model.

4 Results

Mode share varies widely across Toronto, from a high of 29.5% to virtually zero, providing a broad range of outcomes for the analysis. There is also wide variability in income, family size, vehicle ownership and built form, in this large city of 2.7 million people, covering a landmass of 630,2 square kilometers (Statistics Canada, 2016). While suburban areas generally exhibit lower population and employment density, what makes Toronto somewhat unique within the North American context is the abundance of high-density residential towers in its suburbs and the presence of transportation hubs and commercial concentration outside its city core. These polycentric attributes reduce

[1] All spatial autocorrelation tests were conducted using a queen-based contiguity spatial weights matrix, as we rationalized that all TAZs with common boundaries or vertices should be considered as neighbours.

the disparity in trip length and vehicle ownership between inner and outer neighbourhoods.

In **Table 2** we present the coefficients for the reduced and spatial models. The odd ratios can be interpreted as the effect a one-unit change in X has on the odds of Y, whereas the partial derivatives can be seen as the effect a one-unit change in X has on the value of Y (cycling mode share). For instance, if the current cycling mode share in a TAZ is 2%, then a 1.1% increase in the odds of cycling would result a cycling mode share of 2.22%. We also use p-value to report the significance of each coefficient and provide confidence intervals in between brackets.

Table 2: ***Model Results***

Independent variables	**Model 1** Reduced model		**Model 2** Spatial model	
	Odds Ratio (95% CI)	p-value	Odds Ratio (95% CI)	p-value
Constant	0.005 (0.001 - 0.018)	<0.001***	0.006 (0.002 - 0.021)	<0.001***
Spatial lag	-	-	1.091 (1.064 - 1.119)	<0.001***
% of trips <4km	1.044 (1.031 - 1.056)	<0.001***	1.023 (1.012 - 1.034)	<0.001***
% of trips 4-8km	1.044 (1.031 - 1.057)	<0.001***	1.028 (1.015 - 1.040)	<0.001***
Average daily trips per person	1.878 (1.248 - 2.826)	0.002**	1.770 (1.092 - 2.869)	0.021*
Linear density of paved bike lanes and cycle tracks	1.165 (0.988 - 1.375)	0.070	1.195 (1.026 - 1.391)	0.022*
Linear density of recommended or signed on-street cycling routes	1.791 (1.488 - 2.156)	<0.001***	1.452 (1.218 - 1.731)	<0.001***
% of individuals younger than 18	0.985 (0.968 - 1.002)	0.083	0.989 (0.974 - 1.003)	0.121
Average num. vehicles per adult household member	0.160 (0.108 - 0.236)	<0.001***	0.261 (0.178 - 0.383)	<0.001***
% of individuals living in a low-rise house	1.014 (1.009 - 1.019)	<0.001***	1.011 (1.007 - 1.016)	<0.001***
Observations	527		527	
	AIC = 0.2046		AIC = 0.2034	
	BIC = -3233.165		BIC = -3238.029	

Statistical Significance: * p-value <0.05; ** p-value <0.01; *** p-value <0.001.
95% confidence interval between brackets.

Four transportation behaviour variables are found to be significant: the percentage of trips below 4km, between 4-8km, the average number of daily trips per person, and the average number of vehicles per adult household member. The percentages of short trips (those under 4km and between 4-8km) were associated with a 2.3% and 2.8% increase in the odds of cycling respectively. Interestingly in the City of Toronto, where this study takes place, 33% of trips are 1-5 km long, which is highly conducive to cycling (Mitra et al., 2016). Increasing the daily average number of trips per person by one trip was also shown to augment the odds of cycling by 77% and to correspond, using the estimated partial derivatives, to a 1.4 % increase in cycling mode share. Adding one vehicle to the average number of vehicles per adult household member, however, has a negative effect on cycling mode share and is found to decrease the odds of cycling by 74%, and to correspond to a 3.4% percentage point decrease in cycling mode share.

Demographic variables had much less of an impact on determining cycling mode share. Both employment status variables (percentage of individuals working full-time and part-time), gender, and age variables (percentage of individuals aged 18 and under, and those aged 65 and above) were found to be insignificant.

The model further predicts that three physical variables have a significant effect on cycling mode share. A 1% increase in the proportion of individuals living in a low-rise house is associated with a 1.1% increase in the odds of cycling. As expected, the presence of cycling infrastructure is shown to have a positive effect on the cycling mode share. Indeed, a 1km increase in the density of painted bike lanes and cycles tracks in the TAZ or surrounding 1km buffer zone is associated with a 19.5% increase in the odds of cycling, which corresponds, using the estimated partial derivatives, to an increase in cycling mode share of 0.4%. Moreover, a 1km increase in the linear density of recommended or signed on-street cycling routes in the TAZ or surrounding 1km buffer zone is associated to a 45.2% increase in the odds of cycling and an increase in cycling mode share of 0.9%. Our spatially lagged variable is also significant which indicates that a TAZ's cycling mode share is influenced by the level of cycling mode share of neighbouring TAZs. A 1% increase in the average mode share of neighbouring TAZs has a 9.1% increase in the odds of cycling and a corresponding increase in cycling mode share by 0.2%.

In the next section we focus on a specific TAZ that our model predicts should have a high potential for cycling but where this is not actually observed. This case study allows the previous analysis to be connected to the ground truth in the City of Toronto, and enables us to examine how the latent demand for cycling can best be capitalized upon.

5 Analysis of TAZ Case Study

Using the observed vs. modelled cycling mode share values displayed in **Figure 1**, we select a TAZ that displays a lower than expected cycling mode share and investigate this case further. This detailed approach provides concrete demonstrations of the strengths and weaknesses of our regression model and can be used to better inform future cycling policies. **Figure 2** is used to display the case study location and illustrate the extent of existing cycling infrastructure (depicted in green) within the City of Toronto.

Figure 1: Observed vs. modelled cycling mode share

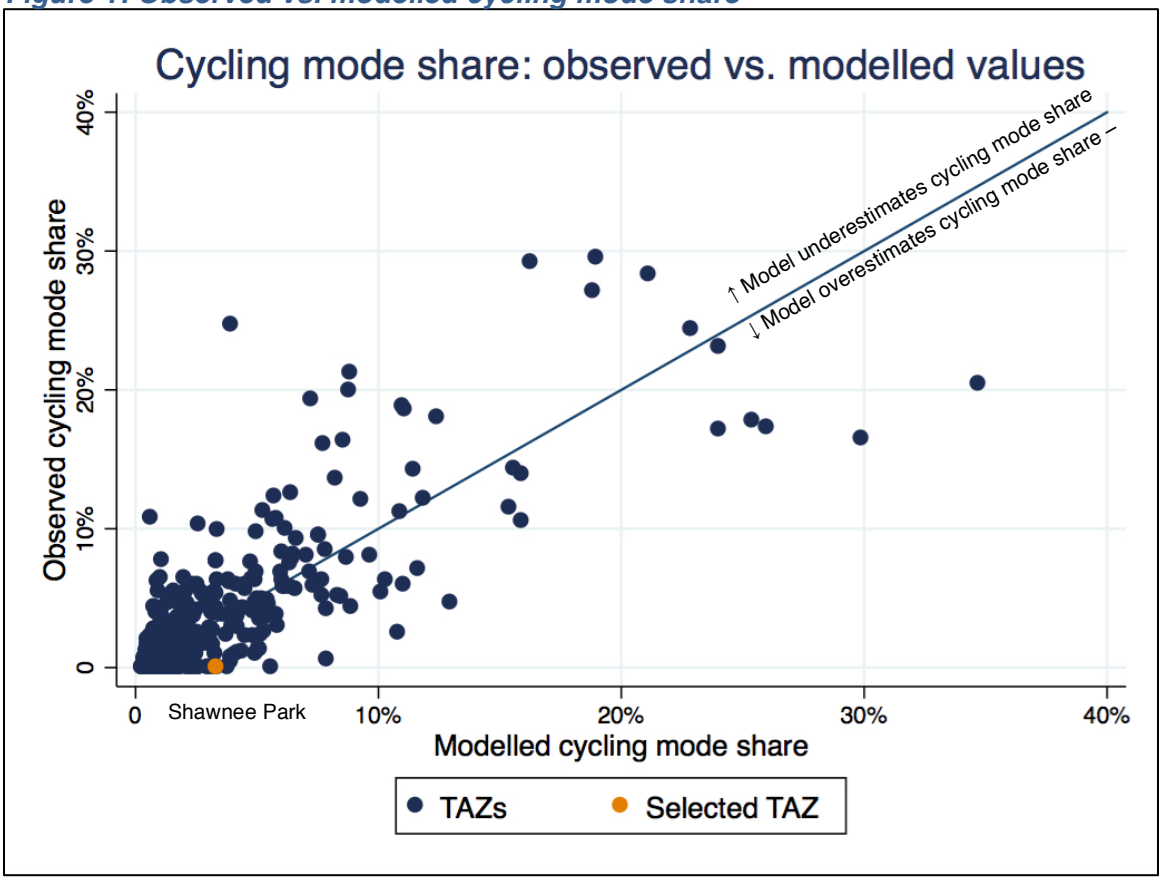
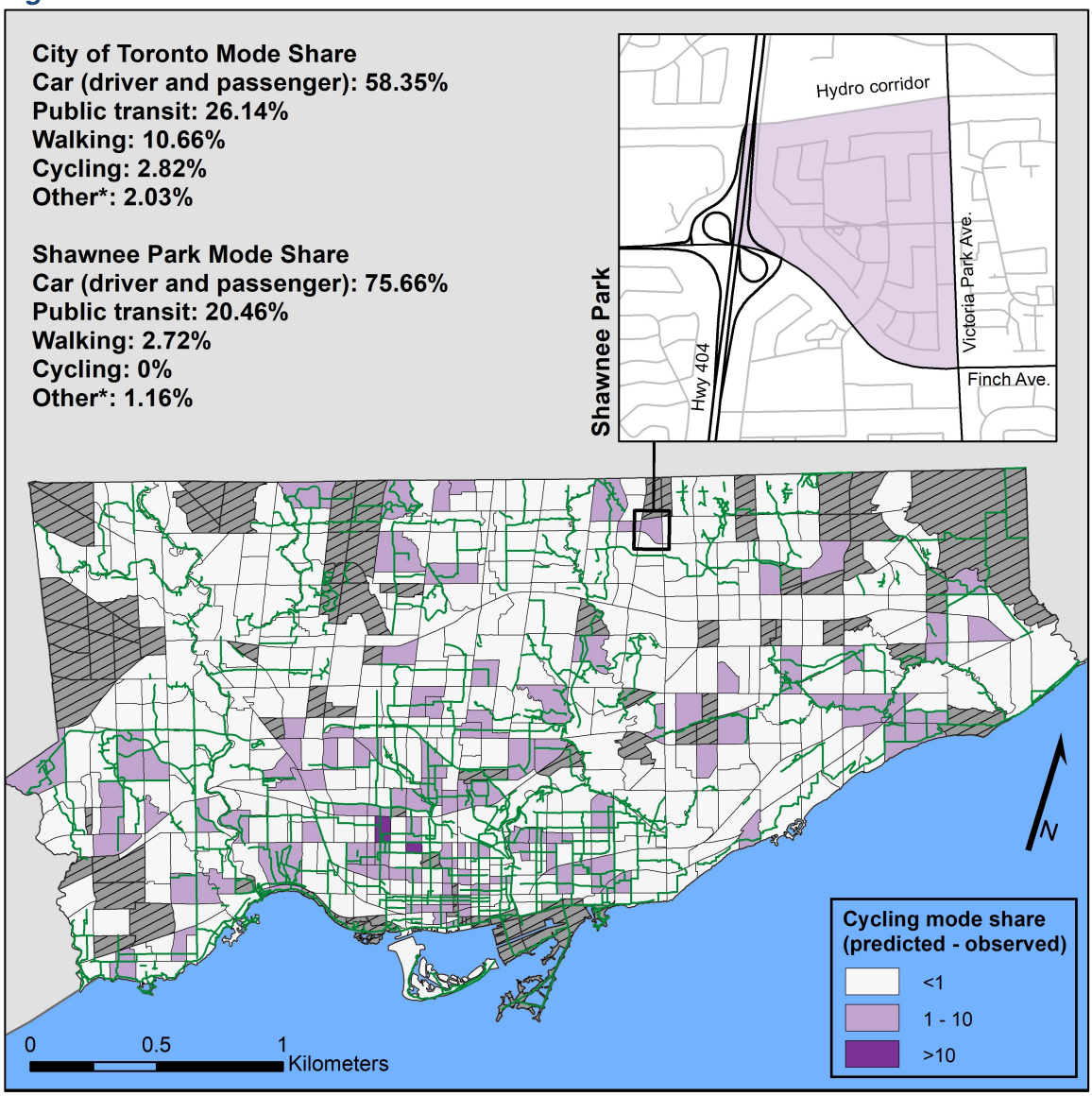


Figure 2: Location of Case Studies



*The *Other* category includes: taxi, ride-hailing, school bus, skateboarding, roller blading, and other rarely used active modes.

5.1 Shawnee Park

Shawnee Park is located in the North Eastern corner of North York – A suburban district located roughly 20km north of Toronto's downtown core. Of the 233 survey results representing the travel patterns of 2,748 residents, Shawnee Park contains no recorded cycling trips. While well below the Toronto average, our regression model does predict a cycling mode share of 3.3% for this area. As our model overestimates the cycling mode share of this area, we infer that it has a high potential for cycling and is therefore where governments should prioritize their investments in cycling infrastructure, policies and programs. To better understand where these investments should be targeted, we further investigate the characteristics of this TAZ.

Shawnee Park is bound by a hydro transmission corridor to the North, the 404 highway to the West, and major arterial avenues Finch and Victoria Park to the South and East respectively. It is a very isolated area, with only four entrance points (one from the south and three from the east). There are no cycling infrastructures in or around Shawnee Park. There is also no way to cross the highway or hydro corridor, which considerably limits the connectivity to adjacent areas and presents a substantial barrier to cycling in this TAZ. Investing in cycling infrastructure to increase the connectivity of this TAZ, especially if combined with cycling adoption programs would likely increase cycling uptake (Kearns et. al., 2019). This could include adding a bike lane along Victoria Park Avenue, adding a bike lane eastwards along Finch Avenue past highway 404 to connect to the East Don River Trail system and implementing a bike hub or mentorship program.

The built form in this area is fairly typical of North American suburbs. Residential streets are organized into loops, and detached one or two storey houses occupy the overwhelming majority of the land. There are no retail stores or industries in Shawnee Park, and the only non-residential land is occupied by a park and two primary schools located in the middle of the TAZ. Despite this, the proportion of short trips (0-4 km) accounts for 40.9% of all trips and is above the Toronto average. While the area's built form limits the number of short trips that can potentially occur in this neighbourhood, it does not prevent governments from introducing cycling to school programs to increase cycling uptake amongst children.

The proximity to the 404 highway renders driving most appealing, which is reflected by the high driving mode share (accounting for 76% of all trips when combining drivers' and passengers' trips). The presence of both local and regional transit stations along the South and East arteries of the TAZ also offer viable transit alternatives, which can be seen by the lower, yet still comparable to the Toronto average, transit mode share of the area (20.5%). Despite this clear automobile dominance, Shawnee Park accounts for a much lower than average number of vehicles per adult household member (1.56) in comparison to the Toronto average (2.1). This may explain why the area is also characterized by a higher than average number of car-passenger trips (13.3%), and would suggest, in accordance with Mitra et al. (2016), that designing transit stations to allow for safe and convenient access and egress by bike could reduce or eliminate automotive trips where the transit user is a passenger.

A careful analysis of this area uncovers its untapped cycling potential, and emphasizes how a few targeted investments in cycling infrastructures and programs can likely lead to cycling adoption.

6 Discussion

The purpose of this paper was to examine factors that may influence cycling uptake and uncover neighbourhoods with a high potential for cycling, as we believe that governments' finite investments in cycling infrastructure, policies, and programs would be particularly effective at increasing the number of new cyclists in these locations. To this end, we conduct a GLM and investigate an area of the City where cycling mode share is underestimated by the model, as this presents the highest potential for cycling adoption.

We find that the frequency of trips (measured by the average number of daily trips per person) is positively associated with cycling mode share, and that this is especially true for short trips (0-4km and 4-8km), as these are the distances most feasible by bike. The number of vehicles per household also impacts the occurrence of cycling as we find that, on average, adding an additional vehicle per adult household member in a given TAZ will reduce cycling mode share by 3.4%. We do not find population density to have an effect on cycling mode share and do not, in accordance with Ledsham et al. (2017), believe that population density is a good predictor for cycling mode share in Toronto. This is because of the City's zoning regulations, which force apartment buildings to locate primarily along fast-moving, multilane arterials that are often not prone to cycling despite their high population densities. This conjecture is further supported by the positive relationship established in our model between cycling mode share and the proportion of low-rise houses. Ledsham et al. (2017) draw similar conclusions and believe that this may be due to the lack of bicycle parking in apartment buildings in Toronto.

Employment status variables (percentage of individuals working full-time and part-time), age variables (percentage of individuals aged 18 and under, and those aged 65 and above), and gender were all found to be insignificant. This finding, or lack thereof, is consistent with previous work by Heinen et al. (2010), which found the relationship between socioeconomic variables and cycling mode share to be ambiguous and to present varying - and at times contradictory – results, depending on the research study's location.

The proximity to transit stations was also found to be insignificant in our model. This is perhaps because it is comprised of two confounding effects, which when considered together, may negate each other's impacts. Indeed, some believe that living in proximity to public transit services will facilitate a carless lifestyle and encourage individuals to replace previous car trips with cycling (Martens, 2007), whereas others find transit to compete with cycling, especially for short trips, and believe that living in proximity to transit will reduce the likelihood of cycling (Pucher and Buehler, 2007; Schwanen, 2002). The combination of both these diverging effects may thus explain the overall insignificance of this variable. It is also possible that a key opportunity for cycling is being missed, as transit stations outside of the downtown core do not generally prioritize cycling for first and last mile, and 7.4 % of current transit rides in the GTHA are made by residents living between 1 and 5 km from their transit station (Mitra et. al., 2016).

The presence and significance of a spatially lagged term in our model indicates that the proportion of cyclists per TAZ is spatially clustered, and may be interpreted as a proxy for social norms regarding cycling in the broader community. The impact of social norms

is well-established in the literature (Wang et al., 2015; Heinen et al. 2010), and captures the way in which a localized growth of cycling ridership may increase the appeal and safety of cycling more broadly through its normalization.

Also shown to have a significant effect on cycling mode share is the presence of cycling infrastructure. A one unit increase in the density of painted bike lanes in and around a TAZ will increase its cycling mode share by 0.4%, and a one unit increase in the linear density of recommended or signed on-street cycling route will increase cycling mode share by 0.9%. Despite not being able to account for the presence of cycling barriers with our dataset directly, the extent of cycling infrastructure within a TAZ serves as a(n inverse) proxy for this variable and appears to be consistent with previous research in finding that an increase in cycling infrastructure will lead to an increase in cycling mode share (Schneider and Stefanich, 2014; Santos et al., 2013).

That being said, the relationship between cycling uptake and cycling infrastructure is not as straightforward as it seems. The high density of cycling infrastructures in central neighbourhoods may partially explain their higher cycling mode share, as incoming residents which value their cycling friendly nature may ultimately decide to move in (Cao and Chatman, 2016), but that does not mean that other areas should be ignored. Government should also consider latent demand for cycling and prioritize neighbourhoods where cycling mode share is currently low but is likely to increase in response to cycling investments. To identify these areas we propose using the model developed in this paper and consider areas with a lower cycling mode share than predicted by our model (i.e. those below the 45 degree line in **Figure 1**) to present a high potential for cycling. These areas, we argue, should also be candidates for government to focus their efforts and investments in order to maximize cycling adoption and increase cycling mode share. A valuable future research contribution would be to track the success of such efforts by measuring the growth in cycling adoption ensuing in such areas from local investments in cycling policy, programs, and infrastructures.

6.1 Limitations

Travel-surveys often underestimate active modes of travel (Handy et al. 2002), and this is also presumably the case for our dataset, as the 2016 TTS only considers the primary mode of travel used for each trip and disregards any secondary modes. This will likely result in an underestimation of cycling mode share, as access or egress trips to transit stations will be entered as transit trips and the survey will omit their cycling component entirely.

Another concern while using a one-day travel survey, such as the 2016 TTS, is that it may miss the day-to-day interactions that explain specific travel behaviours on the day when data were collected (Young and Lachapelle, 2017). For instance, we do not know whether participants commuted by car on the day prior to the survey collection to pursue a multi-purpose trip chain on the way home and get groceries in order to have an errand-free cycling commute on the survey collection day, or vice-versa. In order to address this issue, a multiple-day survey collection is required.

7. Conclusion

This study investigates factors that influence cycling mode share and identifies areas in Toronto that display a high potential for cycling which is not yet capitalized upon. Using a GLM, we determine that the number of vehicles per adult household member negatively impacts cycling mode share and find that the average number of trips, especially those between 0-4km, increases the likelihood of cycling. Our results further support the importance of cycling infrastructure and describe how this will increase cycling mode share locally, but may also increase the share of cycling more broadly as it normalizes this mode of travel, and renders it safer and ultimately more appealing. An area's cycling mode share, however, should not be the sole determinant of the future cycling investments it receives. While investments in such high cycling areas will further increase safety and comfort, our model suggests that government should also focus their efforts in areas with a lower cycling mode share than predicted by our model, as these present a strong potential for cycling uptake. These findings provide broad support for investments in cycling policy, programs, and infrastructure in areas outside of the downtown core, where the density of cycling infrastructure has not yet reached a point of saturation and where much latent demand for cycling remains. Mid town and suburban locations should be strongly considered for cycling investments, bearing in mind the factors identified above in choosing neighbourhoods for investment where car ownership per adult household member is low, short trips are common, and mixed use grid patterned streets ease routing.

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