1   # Mode Choice in Commuter Rail Catchment Areas: Recent Trends
2   # and Role of Policy Interventions in the Greater Toronto Area

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1 **ABSTRACT**

2 This study is focused on investigating the commuter behaviour in areas adjacent to commuter rail
3 service, using GO Transit in the Greater Toronto and Hamilton Area (GTHA) as a case study.
4 More specifically, this study aims at developing a better understanding of the mode split of the
5 commuting trips originating in GO rail station catchment areas and its relationship with various
6 key factors. It also investigates the key trends in mode split over the period of 1996 to 2011,
7 focusing on GO rail mode share and how it is associated with policy interventions. This study
8 used data from four large-scale household travel surveys conducted in 1996, 2001, 2006 and
9 2011 in the study area. Descriptive statistics and a multilevel random intercept model are utilized
10 to achieve the study goals. The study presents a wide range of results starting from the users'
11 walking distances to GO stations to mode split and GO rail mode share association with key
12 variables such as residential density and type of household. It also shows that within the GO rail
13 catchment areas, strategies aimed at improving the local GO service conditions and accessibility
14 had a statistically significant positive association with GO rail mode share. This study offers
15 policy makers and planners a better understanding of the mode share of residents of commuter
16 rail station catchment areas and its relationships with some of the key factors and trends.
17
18
19 **Key words:** Mode Choice, Commuter Rail, Catchment Area, Policy Interventions, Walking
20 Distances

1 **INTRODUCTION**

2 Cities and transport authorities are increasingly investing in new public transit infrastructure and
3 improving existing services, with a prime goal of enhancing the competitiveness of transit and
4 improving its ability to attract auto users, thus reducing roadway congestion and emissions. This
5 study is focused on investigating the commuting mode choice behaviour in areas with high
6 access to high-quality public transit, specifically within commuter rail service catchment areas,
7 using the GO rail service in the Greater Toronto and Hamilton Area (GTHA) as a case study.
8 These areas are considered high potential zones for promoting transit-oriented developments
9 (TODs) in the GTHA (*1*).
10   This study aims at accomplishing two primary goals. The first is to achieve a better
11 understanding of the relationships of commuting trip mode split in GO rail service catchment
12 areas with key factors. Secondly, the study aims at exploring the temporal changes in mode split
13 of the commuting trips originating in GO rail transit catchment areas over an extended
14 timeframe, while focusing on understanding the GO rail mode share association with different
15 factors as well as with GO Transit's policy interventions.
16   This study used data from the four Transportation Tomorrow Surveys (TTS) conducted in
17 1996, 2001, 2006 and 2011. The TTS is one of the largest and most detailed household travel
18 surveys in the world, involving a 5% sample of households in the GTHA. The study is focused
19 on home-based commuting trips made during the morning peak period (between 6:00 and 9:00
20 am) on a regular weekday by individuals of households that are located within GO rail station
21 catchment areas.

22 **STUDY CONTEXT AND METHODOLOGY**

23 The GTHA is the largest and fastest growing urban region in Canada. Home to more than six
24 million people in 2016, the GTHA is projected to reach 8.6 million people by 2031 (*1*). It
25 consists of the City of Toronto and the five regional municipalities of Durham, York, Peel,
26 Halton, and Hamilton. The GTHA is served by 8 local transit networks and a regional transit
27 system for the whole GTHA, known as GO Transit, which includes commuter rail and bus
28 services.
29   The GO rail network consists of seven radial lines (Figure 1), serving more than 100,000
30 daily weekday riders in 2016, with a projected increase to about 225,000-weekday riders in 2031
31 (*2*). In 2011, the Lakeshore West and East lines had the highest daily ridership and service
32 frequency, with two-way, all-day service on all days. In contrast, the other lines had only peak-
33 hour rail service on weekdays, inbound in the morning peak and outbound in the afternoon peak.
34 Outside of peak hours, these corridors were served by commuter bus services (*3*). Accordingly,
35 this study is focused solely on the morning peak period to ensure the availability of GO rail
36 services to commuters living near all GO rail stations across the system.
37   The GO rail network has a strictly radial orientation where all rail lines start or end at
38 Union Station in the heart of Toronto's Central Business District (Figure 1). The Toronto CBD is
39 the main employment centre of the GTHA (*4*), with more than 600,000 jobs in 2016 (*5*). The GO
40 rail system, opened in 1967, has grown over time, with 13 stations added between 1996 and 2011
41 to reach a total of 62 stations in 2011. Over the past two decades, more attention has been given
42 to expanding the GO rail service in addition to improving system operations and access to GO
43 stations at the local level (by foot) and regional level (by car) (*3*). GO Transit, in fact, faces

1 considerable operational challenges in an environment with many freight and intercity passenger
2 trains sharing the rail corridors.
3   Several data sources were used in this study. The first was the TTS datasets of 1996,
4 2001, 2006 and 2011. In each survey year, the TTS gathered information on all persons and trips
5 made on the day prior to the household interview of all household members 11 years of age or
6 older, representing an extensive, ready-to-use and statistically sound basis for describing travel
7 behaviour in the GTHA (*6*). Indeed, the availability of consistent time-series information over
8 such an extended period provides a unique opportunity to explore long-term trends.
9   The second data source is demographic Census Tract (CT) information provided by
10 Statistics Canada from 2011, 2006, 2001 and 1996 NHS- National Household Survey (*7*). These
11 data include information about the number of households and population by CT. The study also
12 utilizes other datasets that provide information on the transportation and street networks. GO
13 Transit service attributes, improvement and policy interventions were captured using GO Transit
14 annual reports and time lines (*8; 9*), City of Toronto reports, news reports and also visually
15 observations using Google earth. To achieve the study goals, we focus on home-based
16 commuting trips made during the morning peak period (between 6:00 and 9:00 am) on a regular
17 weekday by individuals of households that are located within GO rail service catchment areas.
18 Therefore, the first step was to identify the "catchment areas".

19 **Defining Catchment Area**

20   The concept of transit station catchment area is typically used by researchers to analyze
21 transit ridership and assess the impacts of land use developments around transit stations (*10*).
22 Since the GO rail station 'catchment area' is the paper unit of analysis, we define it according to
23 the walking distance patterns of current users. The catchment area size usually varies according
24 to the type of the system (rail vs. bus system) and the associated willingness of users to walk to
25 use the transit service. In the public transit industry, a simplified method for determining service
26 areas is normally used, which is commonly based on an arbitrary threshold distance such as 400
27 metres (0.25 miles) around bus stops and 800 metres around rail stations (*11; 12*), with the main
28 idea that most passengers will walk these distances or less. However, emerging evidence has
29 shown that such arbitrary thresholds often fail to capture many transit users that access the transit
30 system by foot from farther distances (*11; 13; 14*). For example, Burke and Brown (*13*) indicated
31 a median walking distance of 890 metres from home locations to train stations, with the 85th
32 percentile of 1.57 km in 2003 in Brisbane, Australia.
33   In this study, we used the four surveys of 1996, 2001, 2006 and 2011 to assess and define
34 a common catchment area size around GO stations based on the access distance of GO user trips
35 which used "walk" as the access mode. The walking distance was measured using the street
36 network distance from the trip origin to the used GO station. This distance was used instead of
37 the Euclidean distance since the latter normally overestimates the service area because of
38 neglecting the existing street network layout (*15; 16*). It should be noted that due to the fact that
39 the 1996 TTS did not record the actual GO Transit station used by GO riders in the sample, but
40 rather the used GO line, the walking distance to the closest station was used.
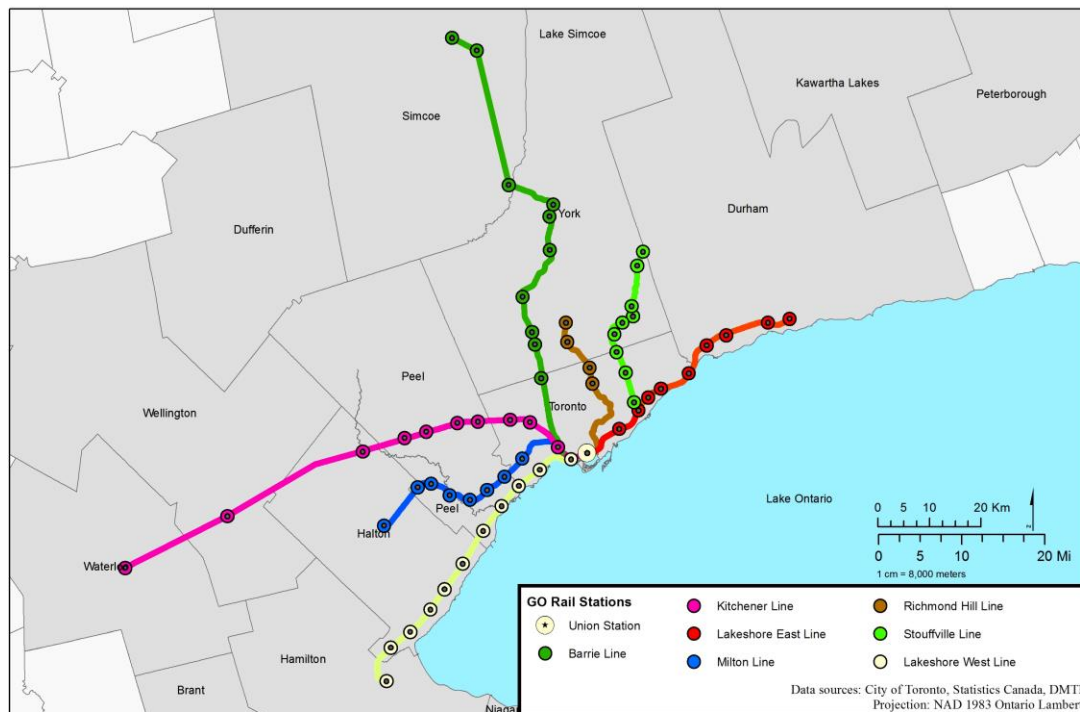
Figure 1: GO rail system map

Current Mode Share Analysis

According to previous transit planning research, several factors are known to be associated with mode split including density factors (e.g., residential density and employment density), land-use (e.g., land use diversity), station design (e.g. layout and parking supply at stations), trip maker (e.g., gender, vehicle ownership), and trip purpose and distance (*17*). For example, population and employment density are identified as the main factors to a higher transit ridership (*18*). Lower levels of automobile ownership are also linked to higher transit usage (*19*), while free car parking at work is related to less transit usage (*17*). Higher parking capacity and lower cost at rail stations are also linked to higher transit mode share (*20*). Accordingly, within our scope of research, and using the most recent available TTS data, namely the 2011 TTS, we investigated the association of mode split with six of the main factors, namely residential density, type of household, parking availability at GO station, car ownership, the availability of free parking at work, and distance to Union Station (km). However, an important step before conducting the analysis is to identify the main transit market share of GO rail users through an examination of the users' locations and destinations. In this paper, the TTS data were expanded to represent the total population using expansion factors calculated as the total number of dwelling units, obtained from the census, in a postal area divided by the number of completed interviews in the same postal area.

Mode Share Key Trends and the Role of Policy Interventions

Over the past two decades GO Transit invested heavily in improving the service within the GTHA (*8; 9*). Therefore, an important aspect was to understand the association between the GO rail mode share and the GO Transit implemented policy interventions. In order to do that, this

1   section first, investigates the trends between 1996 and 2011 in overall mode split and mode split
2   by GO rail line. Subsequently, using a statistical model, the association between the GO rail
3   mode share within the catchment area and GO Transit's policy interventions is explored, while
4   isolating the impacts of a set of influential variables.
5   The model presented in this paper is a multilevel random intercept model. The dependent
6   variable is the catchment area's GO rail mode share in 1996, 2011, 2006 and 2011. Because the
7   model uses data from four separate survey years, panel type data with four separate records for
8   each GO station catchment area can be found. The data have an inherent multi-level structure
9   whereby records corresponding to the different survey years can be considered separate groups.
10   Accordingly, a two-level model is adopted for this study. The upper level represents the survey
11   year and the lower level represents the catchment area. To better understand this model
12   specifications review (*21*). The following is the multilevel random intercept model in which the
13   only coefficient that varies across groups is the intercept α.
14
15       $y_i = \alpha_{j[i]} + \beta_1 x_{i1} + \beta_2 x_{i2} + \varepsilon_i$ $i = 1,.., N, \quad j = 1,.., J$ *(1)*
16
17       $\alpha_j = \mu_\alpha + \eta_j, \text{ with } \eta_j \sim N(0, \sigma^2_\alpha)$ $j = 1, ..., J$ (2)
18
19   where y_i is the station level mode share of GO rail corresponding to observation i, x_{i1} is the ith
20   element of vector x_1 which represents the set of continuous independent variables, x_{i2} is the ith
21   element of vector x_2 which represents the set of dummy independent variables, β_1 is a set of
22   coefficients corresponding to x_1 and β_2 is a set of coefficients corresponding to x_2. α_j represents
23   the model intercept of group j. The intercept α_j is constant for all observations within a group
24   while varying between different groups (i.e., the survey year 1996, 2001, 2006, and 2011). ε_i and
25   η_j are independent households and group error terms that follow a normal distribution with mean
26   0 and variance σ^2.
27   The model was built up gradually. First, a baseline generalized least squares model was
28   generated, whereby GO rail mode share was expressed as a function of an intercept. Then, a
29   second model was generated but while allowing the intercept to vary across different groups in
30   the data (i.e., the survey year 1996, 2001, 2006, and 2011). Finally, the multilevel random
31   intercept model was estimated by expressing GO rail mode share as a function of several
32   explanatory variables.
33   A detailed description of the final variables incorporated in the model can be found in
34   Table 1. Since the model used aggregated data at the catchment area level, several key variables
35   were correlated to each other and thereby only a few of them were incorporated in the model.
36   The removed variables due to correlations include catchment area distance to Union Station,
37   apartment and houses as dwelling types, and auto ownership. A dummy variable, *Major station*
38   *upgrade,* was prepared to account for the major station infrastructure improvements that were
39   done by GO Transit. This dummy variable distinguishes the addition of pedestrian
40   walkways/bridges to improve the station accessibility to nearby locations, the introduction of
41   local bus station loop and dedicated GO rail shuttle service, the construction of a new station
42   building/multi-storey parking lot, and the addition of controlled weather areas to the GO rail
43   platforms. In total, 24 policy interventions were identified. Six of these cases included the
44   provision of additional parking capacity. It should be noted that a policy intervention was linked
45   to the subsequent TTS survey if it occurred at least 9 months before the survey.

1 **Table 1: Description of variables tested in the statistical model**

Variable Name	Description	Mean	Std. Dev.
GO rail mode share	GO rail mode share by catchment and by a 5-year period (dependent variable).	6.45%	4.81%
% of commuters having a free parking at destination	The percentage of commuters who are living in the catchment area and having a free parking at work destinations.	76.67%	9.96%
% of townhouse dwellings	The percentage of the townhouse (as dwelling type) within a catchment area.	8.54%	6.97%
Household density (households/sq.km)	Catchment area household density (households/sq.km)	1294	951.3
Rest of Toronto (dummy variable)	A dummy variable equals one if the catchment area is located within the "Rest of Toronto" region (explained later)		
GO line i (dummy variable)	A dummy variable that equals to 1 when the catchment area is located along line i, where i represents a GO line (only significant variables were kept in the model)		
Major station upgrade (dummy variable)	Dummy variable that equals 1 if a major station upgrade was done in the catchment area's station.		
	Number of records		207

2 **ANALYSIS**

3 **Defining GO Rail Station Catchment Area**

4   Table 2 shows summary statistics of the access walking distance to GO rail stations from
5 all trip origins and separately from home origins. Regarding trips from all origins, the median
6 access walking distance to a GO rail station was 603, 569, 626, and 703 metres in 1996, 2001,
7 2006 and 2011, respectively, while the average walking distance in the corresponding years was
8 1023, 827, 844, and 887 metres. This indicates a positively skewed walking distance, suggesting
9 that the average walking distance does not necessarily represent an accurate representation of the
10 user walking distance. This is expected since some people are willing to walk longer distances
11 than others to access the GO service. The 85th percentile of walking distance to GO rail stations
12 varies between 1386 and 1676 metres.
13   Regarding access walking distance from home origins only, the median access walking
14 distance to a GO rail station was 1059, 1026, 933, and 959 metres in 1996, 2001, 2006 and 2011,
15 respectively, and the average walking distance was 1722, 1312, 1190, and 1161 metres in the
16 corresponding years. These values are all well above the 800 metres used frequently by the
17 transit industry, which indicates that GO users are willing to walk considerably higher than the
18 800-metre threshold to access GO rail stations from home origins.
19   Since this study is focused on how network and land use characteristics in the vicinity of
20 GO stations are related to GO rail usage for commuting trips, a catchment area around each GO
21 rail station was defined based on the observed users' walking distance. Specifically, a network-
22 based distance of 2.0 km, which represents about 85th percentile of users' walking distance in
23 the majority of survey years, was used to define the catchment areas of GO rail stations. This
24 distance is considered adequate for representing a station's primary zone of influence according
25 to the users' walking distance in the GTHA.

1 **Table 2: Summary statistics of access walking distance from all trip origins and from home**
2 **origins to GO Rail stations in the GTHA**

	Walking distance (m) - All trip origins			
	1996	2001	2006	2011
Average	1,023	827	844	887
Median	603	569	626	703
Percentiles:				
75th percentile	1,118	1,020	1,111	1,172
85th percentile	1,676	1,449	1,386	1,437
95th percentile	3,148	2,326	2,273	2,204
Number of records	2,097	3,313	3,487	4,196
	Walking distance (m)- Home origins			
Average	1,722	1,312	1,190	1,161
Median	1,059	1,026	933	959
Percentiles:				
75th percentile	2,274	1,727	1,503	1,508
85th percentile	3,026	2,423	2,127	2,056
95th percentile	4,659	3,346	3,363	2,871
Number of records	376	501	469	515

3 **Location and Destination Matrix for Home-Based Work Trips**

4 This section explores the GO catchment area mode split by region of origin and destination,
5 which is an important point to understand GO rail transit market in the GTHA. Figure 2 shows
6 the mode split of home-based work trips made during the morning peak period by region of
7 origin and destination for commuters who reside within the GO rail station catchment areas. A
8 total of 14,014 records were included in this part of the analysis, representing a total of 295,800
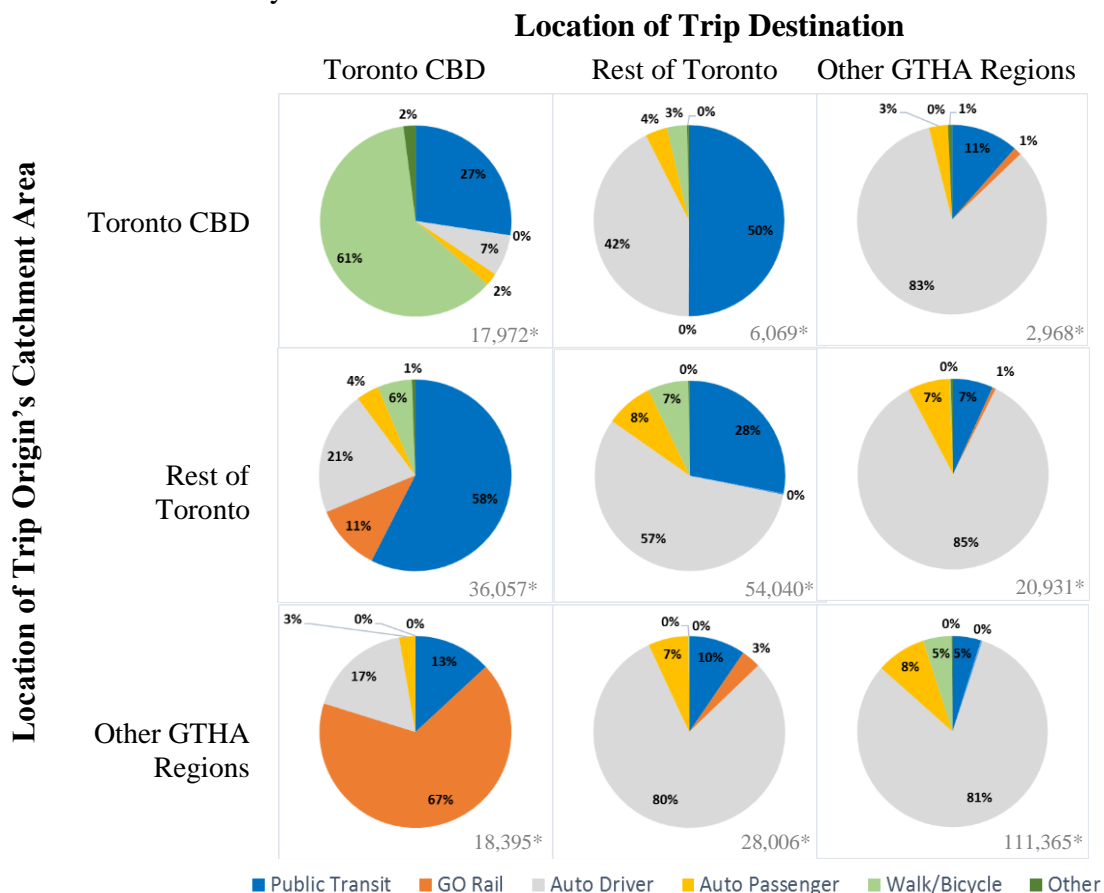9 home-based work trips during the morning peak period in 2011.
10   In this paper, the GTHA was broken down into three regions. The first, "Toronto CBD,"
11 represents the boundaries of Planning District One (PD1), which is the main employment centre
12 in the GTHA. Union Station, the country's largest intermodal transit hub, is located in PD1. The
13 second region, "Rest of Toronto", represents the other 15 planning districts within the City of
14 Toronto and served by the Toronto Transit Commission (TTC)'s multimodal transit system. The
15 third region, called "Other GTHA Regions", includes all other regional municipalities outside the
16 City of Toronto boundaries and within the GTHA.
17   As seen in the figure, most of the AM-peak home-based work trips (88%) originating
18 from the PD1 catchment areas and destined elsewhere in PD1 were made using active
19 transportation modes (walking and cycling) and public transit, with 0% usage of the GO rail
20 service. The GO rail mode share was also at 0% of trips originating in the PD1 catchment areas
21 and destined for the Rest of Toronto, and just 1% of the work trips originating in PD1 and going
22 to Other GTHA Regions. This shows that residents of Toronto CBD rarely used the GO rail
23 service in reverse commuting, and they used mainly local transit or private automobiles to access
24 jobs in the Rest of Toronto and Other GTHA Regions.
25   For the trips destined to PD1 with origins in GO catchment areas in other parts of
26 Toronto, 11% of the trips were made using the GO rail service, while 58% of the trips used
27 public transit (i.e., TTC service). In contrast, 0% and 1% of trips originating in catchment areas
28 in the Rest of Toronto were made using the GO rail service to access jobs located in the Rest of
29 Toronto and Other GTHA Regions areas, respectively.

1   For the trips originating in the Other GTHA Regions, GO Rail was the dominant mode of
2   travel to access the Toronto CBD, with over 67% of all trips made using the commuter trains.
3   This share dropped considerably to only 3% for the trips going to the Rest of Toronto and 0% of
4   the trips going to the Other GTHA Regions. This shows a considerable directional demand for
5   the GO service mainly from the Rest of Toronto and Other GTHA Regions to access jobs at the
6   Toronto CBD during the morning peak period. Therefore, in order to capture and better
7   understand this transit market (i.e., catchment areas in the Rest of Toronto and Other GTHA
8   Regions) the rest of the study is focused solely on all home-based work trips that are made
9   during the morning peak period (6:00 – 9:00 AM) and with origins in the catchment areas of the
10   stations located in the Rest of Toronto and Other GTHA regions. Trips originating in the
11   catchment areas of the stations within the Toronto CBD (i.e., Union and Exhibition GO stations)
12   were removed from the analysis.

Figure 2: Mode split of home-based work trips during the morning peak period by the location of trip origin's catchment area and trip destination (* number of trips).

Relationship of Modal Share with Various Factors

18   This section explores the association of modal usage with different factors, including the
19   catchment area's household density, dwelling type, GO station number of parking spaces,
20   distance to union station, automobile ownership and the availability of parking at work locations.

1 The analysis presented in this section was based on a total of 12,973 records, representing a total
2 of 262,000 home-based work trips that were made during the morning peak period in 2011.
3   Figure 3-A shows mode split by household density, while Figure 3-B shows mode split
4 by dwelling type. As seen in Figure 3-A, the modal shares vary considerably with the household
5 density of the trip origin's catchment area. More specifically, both auto driver and auto passenger
6 usage decline with increasing residential density, while transit and walk/cycle trip-making
7 increase. In contrast, GO rail usage does not follow a clear pattern. These patterns were also
8 observed in the Other GTHA Regions, while for the Rest of Toronto region, higher percentages
9 of trips made by GO rail are associated with less dense catchment areas. As seen in Figure 3-B,
10 the residents of townhouses tend to use the GO service (11%) more than the residents of
11 apartments (4%) and houses (7%) within the GO station catchment areas. In contrast, the
12 residents of apartments tend to use the local transit service and walk/cycle to their work locations
13 more than the other two groups. This can be explained by home location decision issues.
14 Apartment residents tend to have reasonably better access to local transit than dwellers of houses
15 and townhouses, who tend to use GO rail service more.
16   Figure 3-C breaks down mode share by GO station number of parking spaces in 2011 (*3*).
17 As the number of available parking spots increases, so does the GO rail mode share, with a
18 concomitant decline in transit and walk/cycle mode shares. This indicates that locally in 2011 the
19 availability of parking spots at GO stations is associated with higher GO rail service usage for
20 work related trips.
21   Figure 3-D breaks down the mode share by automobile ownership. Residents of
22 households without cars obviously used transit (75%) for the majority of their trips, although
23 active mode (14%) and auto passenger modes (6%) were also used in 2011. For this group of
24 residents who mostly live near GO stations in the Rest of Toronto with excellent and relatively
25 inexpensive local transit service, only 3% of the work trips were made by GO rail service. In
26 contrast, commuters from households possessing a single automobile tend to have nearly 61 % of
27 all trips involving the use of the auto either as a driver or passenger. As the number of
28 automobiles per household increases beyond a single car, the share of work trips made by auto
29 drivers increases dramatically while the share of transit trips drops sharply. It is interesting and
30 informative to see that households possessing a single automobile or more tend to consistently
31 make about 6-7% of trips using GO rail. This shows that GO service is still a viable option even
32 with the possession of more than one car.
33   Figure 3-E shows mode split by the distance to Union Station in kilometres. Farther
34 locations from Union Station see less transit usage and more auto driver usage. The GO rail
35 service usage increases noticeably with the increase in distance from Union Station until it
36 reaches a point, after which it declines. Finally, Figure 3-F shows mode split by the availability
37 of free parking at work. As shown in the figure, residents of catchment areas who have an access
38 to free parking at work tend to drive much more than users with no free parking, who, in turn, are
39 more likely to be both transit users and GO rail users. This highlights the impact of free parking
40 on users' travel behaviour, which is observed elsewhere in the literature (*17*).
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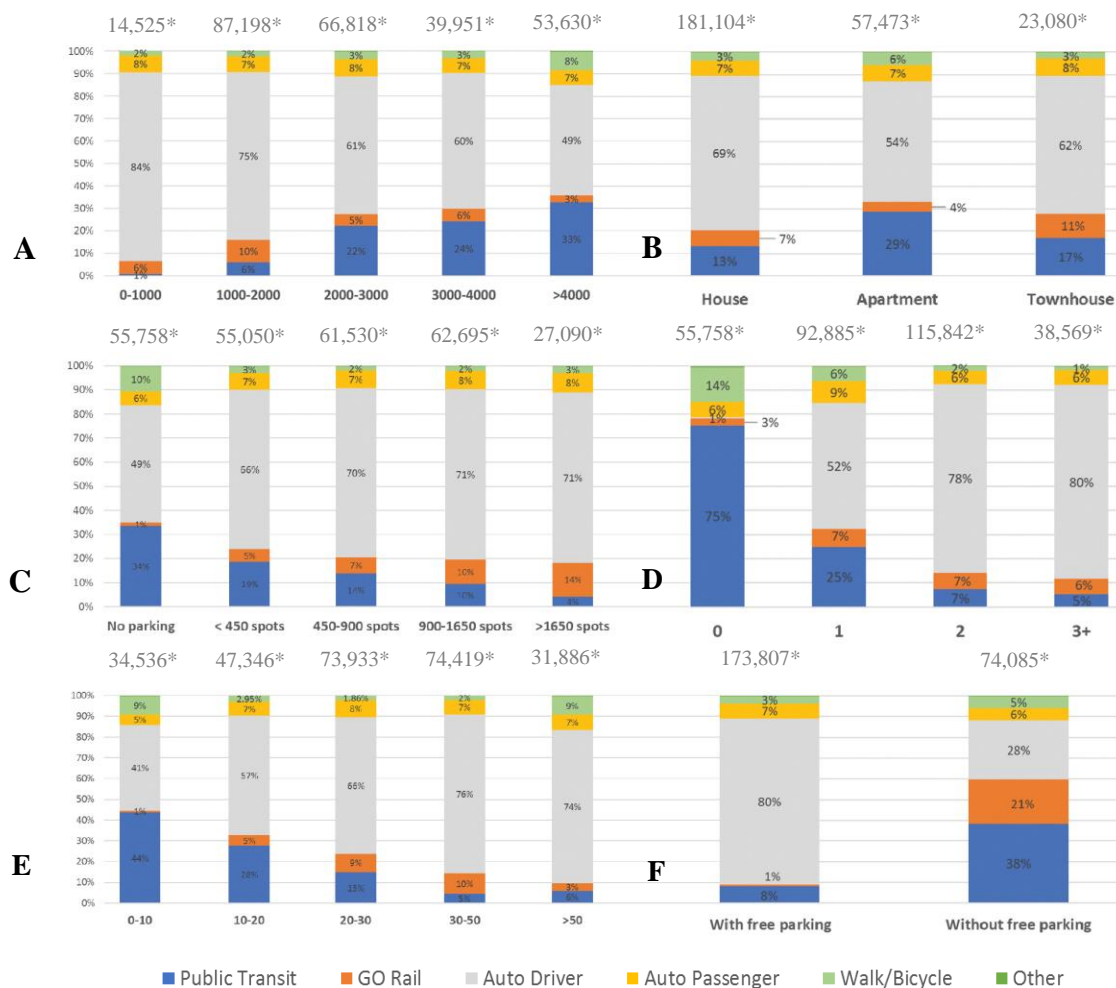
Figure 3: Mode split by: A- household density (households/sq.km), B- dwelling type, C- GO station parking spots, D- auto ownership, E. distance to Union Station (km), and F- the availability of free parking at work (* number of trips)

**Mode Share Key Trends and the Role of Policy Interventions**

In this section, we extend the previous analysis by looking into the key trends that occurred over the period between 1996 and 2011. For the GO station catchment areas, a total of 55,161 records were included in the analysis, representing a total of about 1,053,000 home-based work trips that were made during the morning period between 1996 and 2011. Figure 4-A shows the mode split trends of home-based work trips during the morning period by residents of the GO rail station catchment areas. As shown in the figure, the auto driver share decreased from 67% in 1996 to 65% in 2011. Similarly, the auto passenger mode share decreased consistently over time from 9% in 1996 to 7% in 2011. This loss in auto modal share was offset by an increase in the GO rail mode share, from 4% in 1996 to 7% in 2011. The walk/cycle mode shares remained stable over the years, except for the slight increase from 3% in 2006 to 4% in 2011. Finally, the public transit mode share increased over time from 16% in 1996 to 18% in 2006 then decreased slightly to 17% in 2011. The increase in the GO rail mode share was not exclusive to one line, but rather such increase occurred across all GO lines between 1996 and 2011 (Figure 4-B). To better understand these results the following section investigates some associations between GO rail mode share and a set of variables as well as GO Transit's policy interventions.

1

2
3

A

4
5

B

6
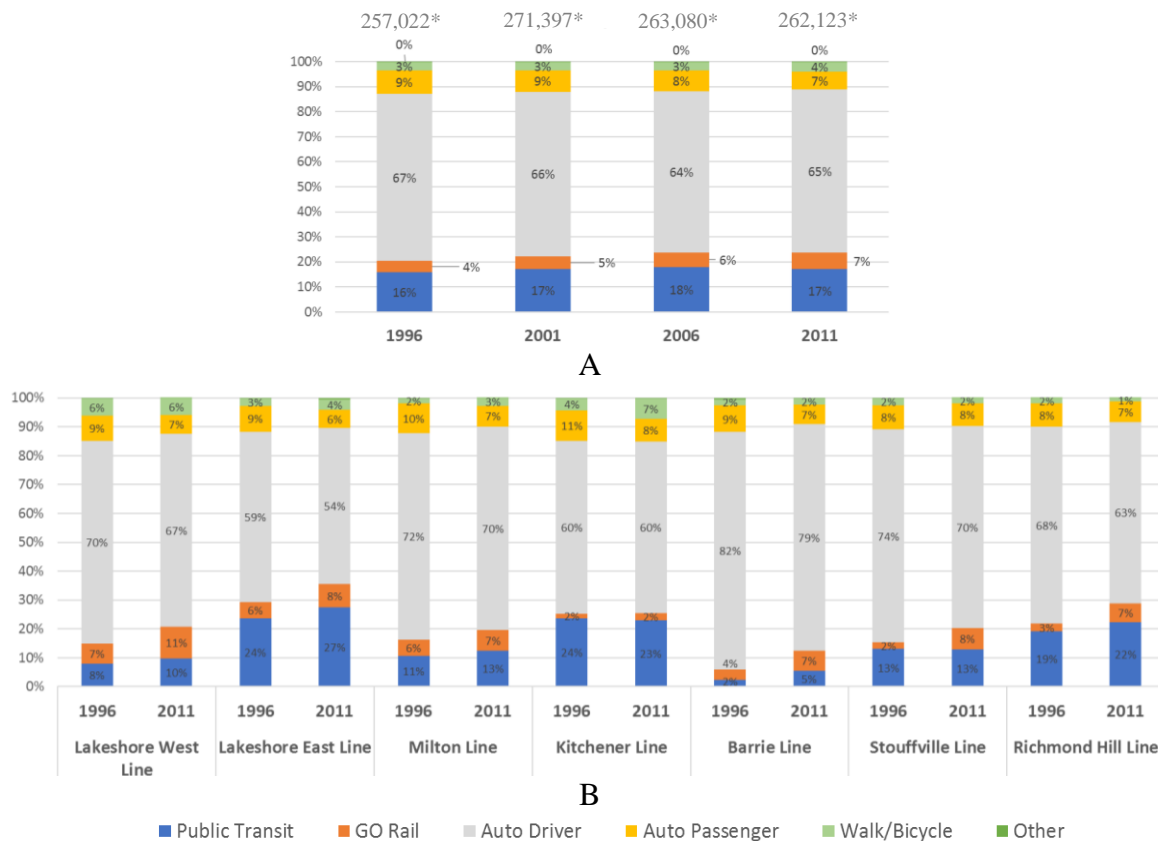
Figure 4: Trends in GO rail station catchment area mode split of home-based work trips -
morning peak period: A- Overall and B - By GO rail line (* number of trips)

9   Figure 5 shows the gain in GO rail mode share by station between 1996 and 2011. The
10 vast majority of stations experienced growth in the GO rail mode share of work trips originating
11 in their catchment areas. Only 7 stations (out of 47 stations, not including Union Station and
12 Exhibition GO station) have seen a slight decrease (less than 2%) or no change in the GO rail
13 mode share between 1996 and 2011. The stations that have experienced increases in the GO rail
14 mode share are distributed across the network, with the highest gains occurring at stations near
15 the City of Toronto boundaries and in the regions of Durham, York, Peel and Halton.
16   A mixed-effect model of transit mode share (as percentage of commuting trips) was
17 estimated using the GO rail mode share by the catchment area as the dependent variable. To
18 build this model, first, a baseline model was estimated for GO rail mode share and expressed
19 only as a function of an intercept. Second, a model was estimated, which also expressed the GO
20 rail mode share as a function of the intercept but allowed the intercept to vary across different
21 survey years (i.e., 1996, 2001, 2006, and 2011). The Akaike Information Criterion (AIC),
22 Bayesian Information Criterion (BIC), and log-likelihood values were compared between the two
23 models. These values were found very similar; therefore, a multi-level random intercept model
24 was estimated. This final model provided us with the best fit in terms of improved AIC, BIC and
25 log-likelihood values and is reported in Table 3. The log-likelihood values of the models are
26 compared using a chi-square difference test. The chi-square value obtained has a reasonable level
27 of significance.
28

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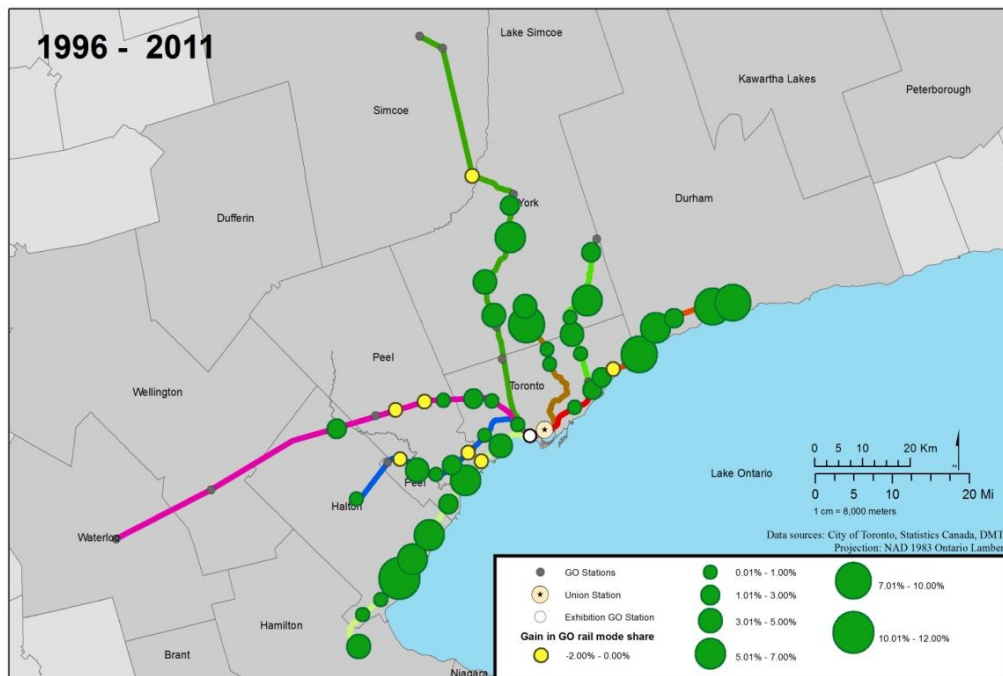
2 **Figure 5: Gains in GO rail mode share between 1996 and 2011.**

3   As shown in the table, the percentage of commuters residing in the catchment areas and
4 have a free parking spot at work destinations shows a negative association with the GO service
5 usage. This finding is perhaps intuitive as free parking at work can encourage commuters to use
6 private automobile at the expense of other modes (i.e., GO transit). GO rail mode share is
7 positively associated with the parentage of townhouses within a catchment area. This can be
8 explained by home location decision issues and users' self-selection behaviour. People may
9 prefer to live at farther locations, but in townhouses, and commute to downtown Toronto using
10 the GO rail. Catchment areas within the Rest of Toronto have a negative association with GO rail
11 mode share in comparison with the Other GTHA Regions. This is expected since residents of the
12 Rest of Toronto region enjoys better transit options provided the TTC multimodal transit system,
13 which would help them to access their destinations in an efficient manner.
14   GO rail catchment area household density has a negative significant coefficient, which
15 suggests a negative association between household densities and GO rail usage. This can be
16 explained by people who live in the denser catchment area are more likely to use other local
17 transport modes than GO rail service for commuting, which we observed in Figure 3. Also, this
18 may reflect that GO Transit is specifically helpful in carrying people from low density areas,
19 which are mainly outside the City of Toronto's boundaries, to Toronto's CBD. Compared to
20 Stouffville, Milton, and Kitchener lines, catchment areas located along Lakeshore East and
21 Lakeshore West lines relatively have a positive association with GO usage, while catchment
22 areas along Barrie and Richmond Hill lines have a negative association with GO usage. This can
23 be attributed to each route specific conditions, nearby traffic volumes and the level of offered
24 service (e.g., Lakeshore East and Lakeshore West lines have the highest service frequency and
25 longest service span among all lines).
26   Regarding GO Transit policy interventions and actions, *Major station upgrade*,
27 accounting for the major station and site improvements, has a positive significant coefficient.
28 This indicates that such station-based improvements had an associated positive impact on the

1 local GO rail mode share while keeping all other variables at their mean values. To demonstrate
2 in more detail the change in GO rail mode share and its relationship to a specific type of
3 improvement, two examples are given. The first, Whitby station, had the highest gain in GO rail
4 mode share during a 5-year period, with an overall increase of 13% between 2006 to 2011 (from
5 9 to 22%). Within this period, GO Transit opened a new four-storey parking lot to boost the
6 station capacity from 1600 to 3000 parking spaces early in 2010. This was also done in
7 conjunction with a site improvement project, and the addition of a bridge, with elevators, to
8 connect the North and South sections of the station. Within the same time period (from 2006 to
9 2011), GO Transit opened a pedestrian walkway across Highway 401 connecting Pickering
10 station south of the Highway with downtown Pickering north of the highway, which dramatically
11 enhanced the station accessibility. Within this time period, Pickering station saw an 8% increase
12 in GO rail mode share (from 10% to 18%).

13 **Table 3: Statistical model**

Variable	Parameter Estimate	t-stats
Fixed effects		
% of commuters having a free parking at destination	-0.157	-3.39
% of townhouse dwellings	0.140	3.72
Household density (households/sq.km)	-0.001	-5.09
Rest of Toronto (dummy variable)	-3.589	-4.45
Barrie Line (dummy variable)	-1.663	-2.17
Richmond Hill Line (dummy variable)	-2.770	-2.53
Lakeshore East Line (dummy variable)	3.467	4.33
Lakeshore West Line (dummy variable)	3.864	5.76
Major station upgrade (dummy variable)	2.578	3.26
Random effect		
Group (survey year, i.e., 1996, 2001, 2006, 2011)	Parameter Estimate	Standard Deviation=0.434
Random Intercept (mean)	19.832	t statistic = 4.89

14

15 **SUMMARY OF KEY FINDINGS AND POLICY IMPLICATIONS**

16 The main objective of this article is to present a better understanding of the mode split of the
17 commuting trips originating in GO rail transit catchment areas, and the key trends in the mode
18 split that occurred over the period between 1996 and 2011 while focusing mainly on the GO rail
19 mode share. In order to do that, the analysis used four TTS datasets collected in 1996, 2001,
20 2006 and 2011, while focusing on home-based work trips that were made during the morning
21 peak period (between 6:00 and 9:00 am) on a regular weekday by individuals of households
22 located within catchment areas of all GO Rail stations. In this study, we define the catchment
23 area according to the 85th percentile of the GO rail users' access walking distance to GO rail
24 stations in the GTHA. The key findings and policy implications of the paper are summarized
25 below.
26   GO rail users walked longer distances from home origins to reach GO rail stations than
27 from all other origins, which exceeded the common standard of 800 metres. This finding is
28 consistent with other studies which reported a similar pattern of long walking distance to rail

1   stations (*13*). Therefore, identifying an adequate buffer is needed in order to accurately capture
2   most of the local users' socioeconomic factors. In addition, policies should encourage users and
3   reflect their willingness of walking farther distances to rail stations by providing a better walking
4   environment and knowledge about its positive health impacts.
5   Using the TTS survey of 2011, the study shows that catchment areas with higher levels of
6   household density have higher shares of work trips made by sustainable transport modes
7   (walk/cycle and transit). However, the GO rail service mode share of work trips originating in
8   GO catchment areas does not seem to be strongly associated with the above-noted result.
9   Similarly, GO rail usage (relative to other modes) is not strongly associated with the private
10 automobile ownership level beyond the one automobile per household. In contrast, catchment
11 areas that are located further away from Union Station enjoy a higher GO rail mode share.
12 However, after a certain point, the GO rail usage relative to other modes starts to decline sharply,
13 highlighting the range of GO rail's travel market where the service seems to be reasonably
14 competitive with other modes.
15   Catchment areas of GO rail stations with higher parking capacities have higher GO
16 service mode shares of trips originating in these catchment areas, while the availability of free
17 parking at work locations has a negative association with GO rail usage. Therefore, making the
18 most efficient use of land around stations by providing sufficient parking space, while
19 establishing more supportive land use patterns for denser and mixed-use development, is
20 recommended. This would support a balanced market of various groups of riders (e.g., walkers,
21 cyclists, auto riders and transit riders) within the catchment areas. Also, policies that restrain
22 free parking availability at work, when other options exist (i.e., transit and GO service), are
23 recommended.
24   Using a statistical model, the paper investigated the association between GO rail mode
25 shares and GO Transit used policy interventions. The model indicated that locally, within the
26 catchment areas, policies and strategies that aimed at improving the service conditions and
27 accessibility were associated with an increase in the local GO rail mode share. These results
28 show that GO Transit between 1996 and 2011 was successful in growing its market share in its
29 station catchments areas by employing station-based improvements. In addition, the model
30 shows that within the GO rail catchment areas, higher household densities were not associated
31 with the increase in GO rail mode share. In contrast, GO mode share with positively associated
32 with dwelling type, namely with townhouses, highlighting the importance of considering
33 possible users' self-selection behaviour while understanding commuter rail mode share.
34   This study investigated the association between the GO rail mode change and policy
35 interventions over a period of 15 years, which did not allow us to investigate in more detail the
36 impact of each individual strategy on mode share. In other words, we have grouped different
37 strategies (i.e., site-based, platform-based, station-based) into one variable "Major station
38 upgrade" in order to have a representative sample that can be used in the statistical model.
39 Therefore, using the same methodology for a longer period of time, while capturing the
40 association between different groups of strategies with rail service mode share, is recommended.
41 Also, this study focused solely on understanding the changes in the commuting mode choice and
42 its association with several variables. Therefore, another study that extends the analysis to
43 investigate the key trends of GO rail service access mode choice is recommended. Finally,
44 although the context of this study is the GTHA, Canada's largest urbanized region, other regional
45 transit authorities can benefit from this study. By utilizing a similar methodology and type of

1 data, they can analyze travel patterns and trends specific to their geographic and operational
2 contexts.

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AUTHOR CONTRIBUTION STATEMENT

9 The authors confirm contribution to the paper as follows: study conception and design: Amer
10 Shalaby, Khandker Nurul Habib, Ehab Diab and Saidal Akbari; data collection: Ehab Diab and
11 Saidal Akbari; analysis and interpretation of results: Ehab Diab and Saidal Akbari; draft
12 manuscript preparation: Amer Shalaby, Khandker Nurul Habib, Ehab Diab and Saidal Akbari.
13 All authors reviewed the results and approved the final version of the manuscript
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