UNIVERSITY OF TORONTO

Fare-based Transit Assignment Models: Comparing the Accuracy of Strategy-based Aggregate Model EMME, Against Microsimulation Model MILATRAS

Prepared by

Peter J. Kucirek

Supervised by Eric J. Miller

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ABSTRACT

Transit fares are important factors that affect a transit user's decision-making process. Given the wide variety of structures used by transit operators, this makes modelling the effects of fares on travel behaviour accurately both difficult and necessary.

This paper looks at two fare-based transit assignment models (GTA Model Version 3 and MILATRAS), and compares them against surveyed trip-record data in order to measure the accuracy of their route choice algorithms. GTA (Greater Toronto Area) Model v3, the primary modelling framework used in Toronto, Ontario, Canada, is implemented in EMME. MILATRAS is an agent-based (microsimulation) model developed recently at the University of Toronto.

To test these models, inter-municipal crossing the border between Toronto and Mississauga were modelled on three transit operators' networks: GO Transit, Mississauga Transit, and the Toronto Transit Commission.

It was found that the EMME transit assignment algorithm significantly over-predicts the number of transfers between operators (with different fares), particularly between local (non-premium) operators. MILATRAS assignment results were, on average, more accurate; over-predictions of trips with more transfers were offset by under-predictions of trips with fewer transfers.

ACKNOWLEDGEMENTS

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1.0: INTRODUCTION

Transit fares are important factors in a person's decision to use transit; they are one of the most direct costs considered. However, there is great flexibility in how transit fares are structured. Some jurisdictions use flat-fares, others are distance-based. This makes modelling the effects of fares on travel behaviour accurately both difficult and necessary.

The most recent implementation of the Greater Toronto Area Model (GTA Model) - which is the primary modelling framework for transportation modelling in the metropolitan region surrounding Toronto, Ontario, Canada - incorporates fare-based transit assignment. However, limitations imposed by EMME, the software package used for transit assignment, limit the flexibility, explainability, and potentially the accuracy of the trip assignment procedure. In addition, research at the University of Toronto - where the GTA Model was developed by Eric Miller - has been exploring the application of microsimulation (also known as agent-based) models to transportation planning. Therefore, it is advantageous to apply a microsimulation model to the problem of fare-based transit assignment.

This thesis will look at one such model, also developed at the University of Toronto by Mohamed Wahba: MILATRAS. In order to examine and compare the accuracy of the fare-based transit assignment algorithms used in MILATRAS and in EMME, individual trips, with known route choices will be assigned in each model, and the results compared against the actual route choices.

This document is roughly split into four parts: Section 2 provides some background information about the models being studied; Section 3 describes the methodology used to produce results; and Section 4 presents these results and their significance.

1.1: Scope of Work

This report will look at morning peak period trips, travelling from the City of Mississauga to the City of Toronto (and vice-versa), which have used at least one TTC route. These limitations are imposed due to the current implementation of MILATRAS, whose network only implements the TTC and GO networks (see Section 2.1), and whose set of trips is currently limited to morning peak period trips which have used at least one TTC route. The GTA Model already includes all transit operators and routes in the GTA and therefore imposed no limitations.

The set of trips analyzed in this paper are a subset of the trips modelled in MILATRAS, filtered by those trips crossing the boundary between the Cities of Toronto and Mississauga. At least one other local operator was required in order to test the full range of transfer types possible in the GTA. Mississauga was selected because of its proximity to Toronto, and its size (it is the second most-populous municipality in the GTA) - and also due to the author's familiarity with the City.

Lastly, this paper will be focusing on route choice as one aspect of transit travel behaviour affected by fare-modelling. Other measurements of accuracy of modelling fare-based assignment exist, however they will not be looked at due to data and time constraints.

2.0: BACKGROUND

Section 2.1: GTA Transit Fare Structures

The Greater Toronto Area is the largest metropolitan region in Canada, with most municipal jurisdictions providing some level of local transit operations. Of these, the Toronto Transit Commission (TTC) is the largest transit operator in the region by ridership, and it is under the jurisdiction of the City of Toronto. The TTC operates an extensive multimodal network, which includes streetcars, subways, and buses. With exception of some premium express bus routes, the TTC uses a flat-fare payment system; users pay once for entrance to the system. This is similar to the fare systems used by other transit operators within the metropolitan region - although different fares are charged to the users.

In addition, Government of Ontario Transit (GO) is a regional operator that runs regional bus service and commuter train service. GO Transit's commuter train is radially-oriented, serving rush-hour traffic into Toronto's Union Station in the morning, and out from in the evening. GO Transit uses a zone-based fare system, which is approximately fare-by-distance.

2.2: Fare-Based Transit Assignment in GTA Model version 3, Implemented in EMME/3

As its name implies, the GTA Model is a travel demand forecasting model for the Greater Toronto Area (GTA). The entire GTA Model framework goes far beyond the traditional four-stage travel demand forecasting model described in literature, however much of the model is outside the scope of this paper. Instead, the focus is on the fare-based transit assignment procedures which have been implemented in EMME for Version 3 of the model.

EMME, which stands for “Equilibre Multimodal, Multimodal Equilibrium,” is a standard transportation modelling software package used throughout the GTA. EMME/3 is the most recent version of the software, and it includes a more user-friendly graphical interface over its predecessor, EMME/2. The transit assignment algorithm implemented in EMME/3 is based on the concept of optimal strategies (Spiess, 1984; Spiess and Florian, 1989). Within this framework, a strategy is defined as a series of rules that a traveller applies to get to his or her destination (INRO, 1998); the concept acknowledges the fact that there are often multiple paths available to a trip-maker and that path choice is not necessarily based on finding the single path that results in the shortest travel time. Although theoretically, the amount of detail accounted for in a strategy varies with the amount of information available to a traveller, in EMME a strategy can be thought of a 'tree' of boarding nodes, alighting nodes, and links connecting these nodes. Each branch in the tree is assigned a probability based on the frequency of the route relative to the total frequency of all attractive routes at the node.

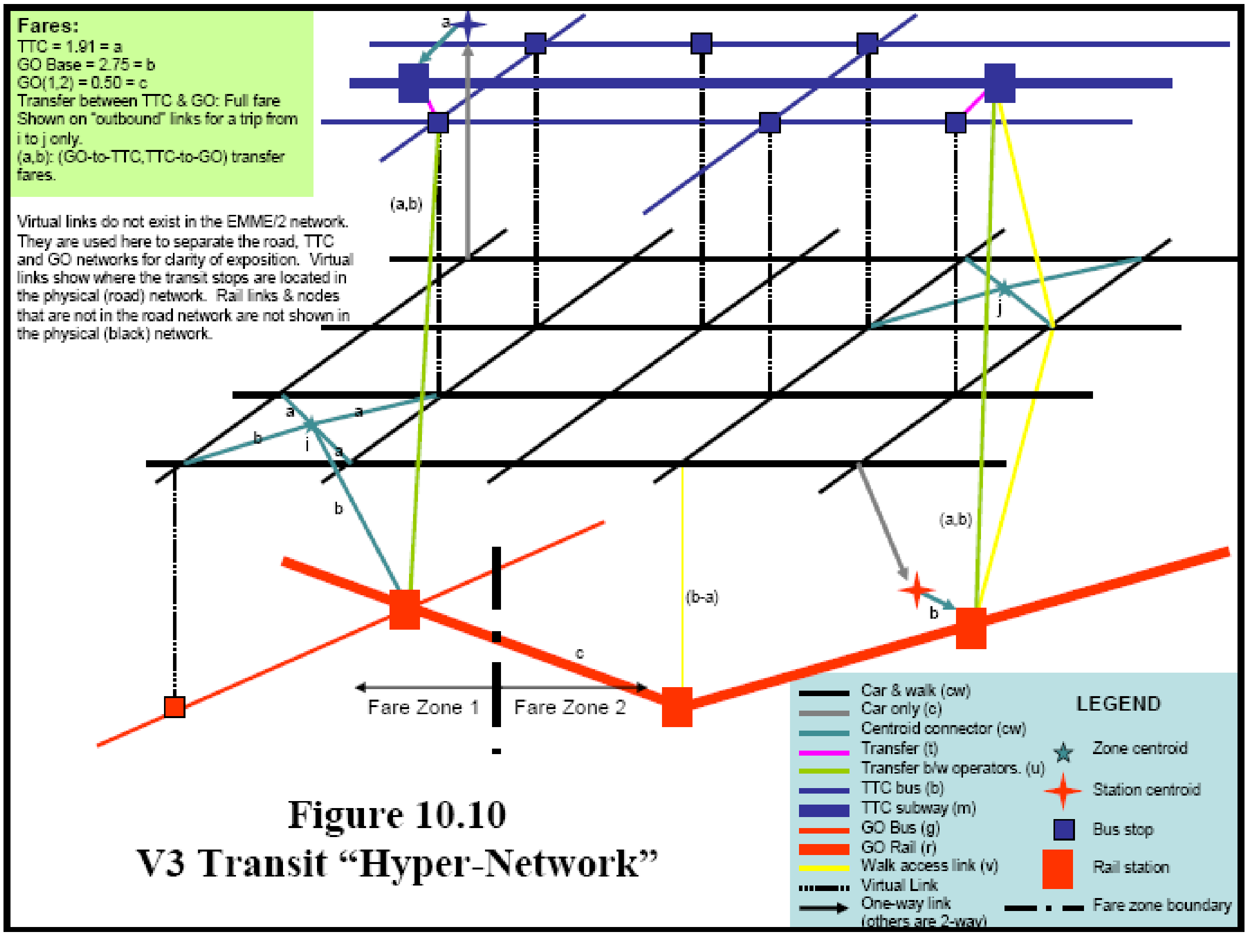

Figure 2.1: V3 Transit "Hyper-Network"

For fare-based assignment within this framework, travel time was used as a general disutility measure. In other words, monetary fares had to be converted, using a Time-Value of Money (TVM) to a measure of time. However, the greatest challenge of modelling the effects of transit fares on travel behaviour in EMME was in ensuring that the correct fare-costs were incurred by travellers. This is a challenge because of how EMME calculates the impedance variable used in the assignment. Essentially, EMME can assign a 'boarding penalty' - measured in minutes - but it applies the same boarding penalty function *every time a traveller boards a* *transit vehicle* (Miller, 2007). This is a challenge for fare-based assignment in the GTA because in flat-fare systems, the transit fare cost is applied on the first boarding of a transit operator.

The solution implemented in Version 3 works around the limitations imposed by EMME with the use of *connectors*, or links with no physical analogue that represent access, egress, and transfer penalties. In typical applications, connector links are used to connect origin and destination travel zone centroids (ie, nodes where trips start and end) to the rest of the network. Version 3 adds a *virtual* length to connectors leading *from* a centroid, representing the disutility incurred by boarding transit. In addition to centroid connectors, Version 3 created virtual connectors, first by modifying the network so that nodes and links shared by two or more operators were split apart, then by linking all operator transfers at these nodes with the virtual link.

Essentially, this converted the 'flat' EMME network into a collection of layers, one for each transit operator, with virtual links connecting each layer (See Figure 2.1). The complexity of this procedure is one of the primary reasons for validating MILATRAS as a potential successor to EMME as a transit assignment program.

2.3: MIcrosimulation Learning-based Approach to TRansit ASsignment (MILATRAS)

MILATRAS is a microsimulation transit assignment program which simulates the behaviour of a population of individual agents. This is very different from older transit assignment algorithms like EMME, which predict how passengers choose their routes and extrapolates to assign multiple passengers simultaneously. It employs concepts from artificial intelligence to simulate how each agent learns from and reacts to its travel choices and consequences (Wahba, 2008). An excellent overview of MILATRAS is given in (Wang 2009) in more detail; additional information can also be found in (Wahba 2008).

Fare is represented in MILATRAS as part of the Generalized Cost (GC) formulation. MILATRAS uses a nested tree of different types of "state-action pairs," which can be thought of as nodes in a nested tree (See Figure 2.2). Each state-action pair has an associated GC, which takes the general form:

GC = Fixed immediate cost + expected immediate cost + expected future return (Wahba 2008)

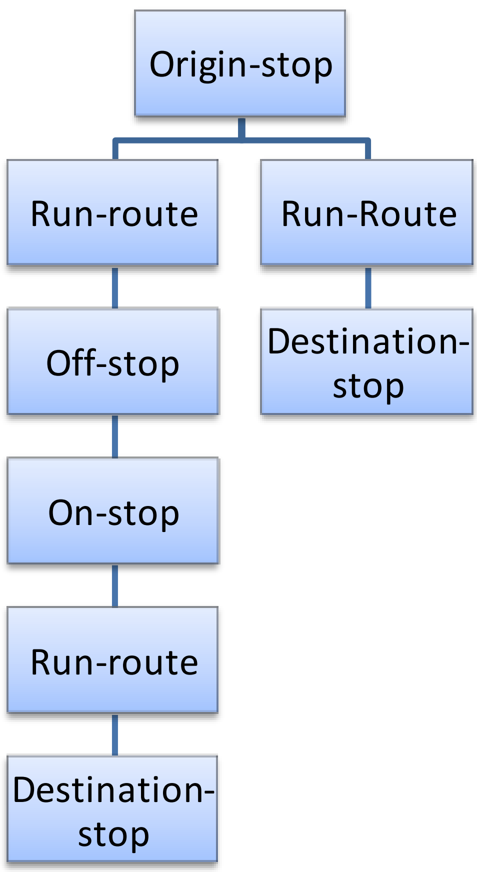

Figure 2.2: Milatras GC Tree

Fares are fixed, immediate costs for the "Origin-stop," "Off-stop," "On-stop," and "Destination-stop" pairs.

From this formulation, it is clear that MILATRAS can represent the main two fare structures in use in the GTA in a manner much closer to reality than EMME. For example, for flat-fare systems, only the 'origin-stop' fare is paid, or paid when transferring at/to 'on-stop.'

3.0: METHODOLOGY

3.1: Overview of Methodology

This section describes what data was used, and how it was analyzed to produce the results presented in Section 4. First, Section 3.2 describes the sources of data used in this paper and the input into each model; Section 3.3 describes the assignment procedures used in each model as well as the parameters used; and Section 3.4 describes the procedure used in analyzing the output of the models.

In order to analyze the effects of fare-based transit assignment on route choice, the desired output from the modelling process has to be similar to the set of observations - namely, a sequence of routes taken from origin to destination. To produce these results, the following general steps were followed:

1. Observed trip data was obtained, filtered, and prepared for assignment
2. EMME and MILATRAS models were prepared for assignment
3. Individual trips were assigned to both models
4. Results for each model were obtained
5. A program was written to transform model outputs into a format compatible with observations.
6. The results were analyzed, looking at key measures of accuracy.

3.2: Data Source & Model Input

All data, wherever possible, is for the year of 2001. This year was chosen because the MILATRAS model is primarily implemented for 2001, and it is necessary to ensure that the models were at least spatial equivalent for experimental control. For this paper, the categories of data were obtained: Data required for analysis, model input into MILATRAS, and model input into EMME. Model parameters will be discussed in Section 3.3.

3.2.1: Data Required for Analysis: Individual trip data was obtained from the 2001 Transportation Tomorrow Survey, courtesy of the Data Management Group at the Joint Program in Transportation, University of Toronto. The subset of data used in this study only included trips which met the criteria listed in Table 3.1. These criteria were selected to match the scope of analysis described in Section 1.1. A total of 714 individual trips met these criteria.

Table 3.1: List of trip criteria

Variable		Values
Start Time of Trip	=	6:00 AM to 8:59 AM
Trip origins, trip destinations	=	Mississauga to Toronto or Toronto to Mississauga
Has used a TTC Routes	=	True

3.2.2: Model Input for MILATRAS: Network data for Mississauga had to be encoded for input into MILATRAS, as discussed in Section 1.1. The two files MILATRAS uses to define its network are a list of stops, with coordinates[1]; and a list of routes and their attributes. Routes in MILATRAS are defined by a sequence of stops, with the 'as-the-bus-drives' distance between each stop. Route and stop GIS data was provided courtesy of Mississauga Transit, as well as stop sequences for each route. However, distances between each stop had to be calculated. ArcGIS software was used to automatically calculate distances from each stop.

Data obtained from Mississauga Transit was for 2008, therefore the list of routes had to be filtered to ensure spatial parity between MILATRAS and EMME (stop data were retained,

[1] The coordinate system used in MILATRAS is UTM NAD1983, Zone 17N (metres)

however, as there were no 2001 data set to compare with). In addition, some routes have been discontinued since 2001, and others were significantly different. These routes required heavy editing to match the route definitions used in EMME. A list of all of the routes used in this analysis can be found in Appendix A.

Lastly, MILATRAS requires three attributes for each route: route headway, average route speed, and time of arrival of the first vehicle at the first stop, measured in seconds past midnight. Headways and average speeds were taken directly from analogous EMME routes, while start times were taken from schedule data provided by Mississauga Transit.

3.2.3: Model Inputs for EMME: Since the GTA transit network is already well-defined in EMME, no changes were made to the network. The only input file required was a list of individual trip records, with their origin and destination coordinates[2], as well as the network nodes of access and egress. As discussed in Section 3.3, the analysis module used in EMME can accept multiple potential access and egress nodes, typically based on a radius centred on the origin/destination coordinates. In this analysis, however, access nodes and egress nodes were set to the origin/destination zones, respectively, of each trip. This was done to ensure that the module results are consistent with the standard transit assignment procedures, which only uses origin/destination zones.

3.3: Model Specifications

3.3.1: Parameters: EMME and MILATRAS use a different set of parameters (for example, weight time weight in EMME, or transfer penalty weight in MILATRAS), however no

[2] The coordinate system used in EMME is a modified UTM NAD1983, Zone 17N (metres); the first digit of all y-coordinates is dropped as the EMME databank only accepts 6-digit coordinates.

modifications were made to the existing parameter sets for both models. It has been demonstrated that despite variability between certain parameter values, the results are statistically similar (Wang, 2009).

3.3.2: MILATRAS Modelling Procedures: MILATRAS runs were not performed by the author, instead MILATRAS was run with the modified Mississauga Transit & TTC network by its creator, Professor Mohamed Wahba.

3.3.3: EMME Modelling Procedures: Module 5.35 was used in EMME for transit trip assignment. This module is a slight modification of the standard transit assignment (Module 5.31), which allows for trips to be assigned to their actual origin and destination coordinates rather than the traffic zones in which the access/egress. The underlying transit assignment algorithm remains the same for each (INRO, 1998).

3.4: Analysis Methods

Both models output a strategy for each trip record as a trip tree of multiple paths, although in slightly different formats. In order to conduct proper analysis, a program was written to parse the outputs and translate them into similar formats. The program stored each trip strategy into a nested tree-structure, and then 'resolved' each trip into a set of paths to travel from origin to destination (see Figure 3.1). For EMME, the program also assigns a weight to each path, which is used later in the numerical analysis to determine the weighted average for various measures. It is simply the fraction of volume which EMME assigns to each path (with the sum over all paths equal to 1.00). This was chosen because the EMME transit assignment algorithm assigns all the volume of each trip simultaneously; volumes as assigned

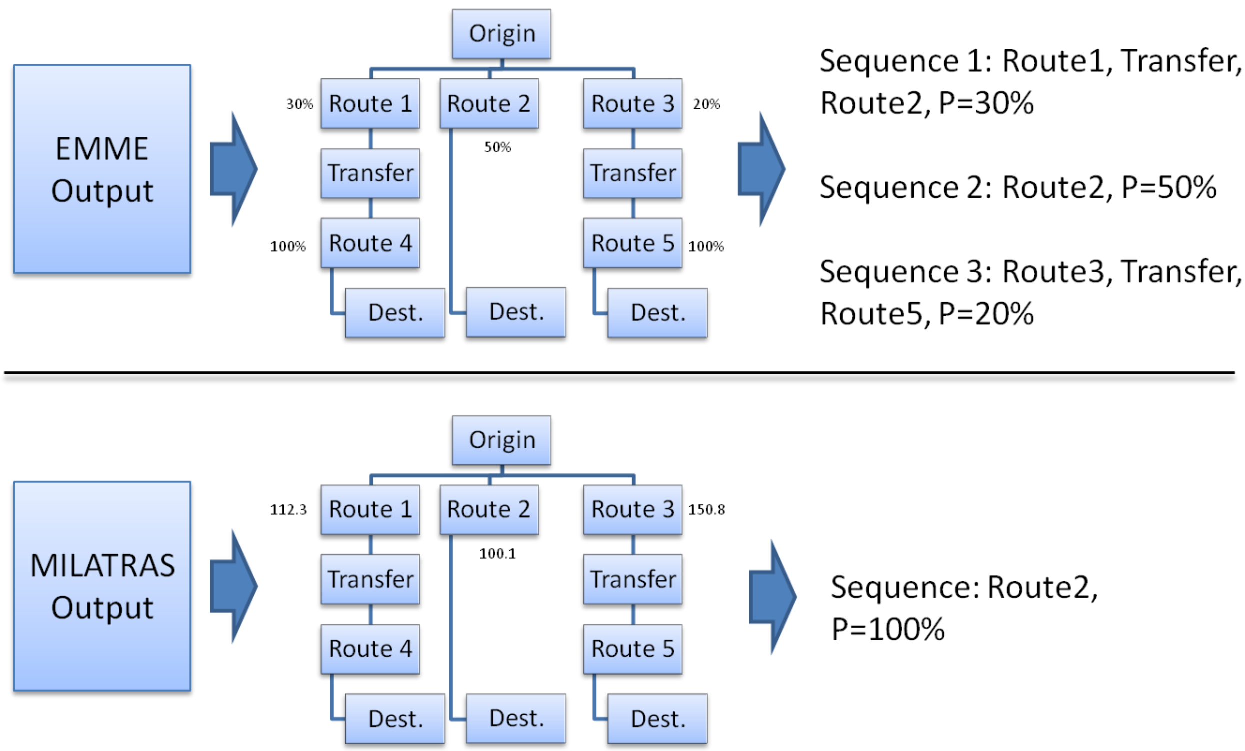

Figure 3.1: Analysis Program Flowchart

linearly according to the probability of choosing each path (INRO, 1998). Thus, it should follow that a similar weighting procedure is appropriate.

For MILATRAS, the program 'resolves' the trip tree into a single path, selecting a single path based on the minimum Generalized Cost (GC). This is appropriate to MILATRAS because MILATRAS *does not* assign volumes simultaneously; instead, each trip-maker only takes *one* path each iteration. The choice methods used by MILATRAS are out of the scope of this paper, and the GC measure is the best available predictor of the path chosen by the most recent iteration.

<u>4.0: RESULTS & DISCUSSION</u>

This section presents the results obtained from the analysis procedure outlined in Section 3. Four different sets of measurement were taken: number of operator transfers, number of route transfers, and the breakdown of transfers by operator for each dataset. All measurements are compared in some way against individual trip records.

A quick note regarding results from EMME: since the results from EMME are weighted, the values for any measurement are typically non-integers. To make these results compatible with the integer results from TTS and from MILATRAS, EMME results have been rounded up or down to the nearest integer value.

4.1: Operator Transfers

Transfers between transit operators (such as TTC to GO) is a key behaviour affected by fare-based modelling. In this analysis, the number of times a trip-maker transfers from one operator to another is counted; Figure 4.1 shows a histogram of the results. It is immediately clear that EMME over-predicts operator transfers; there are very few trips which did not have at least one transfer from one operator to another. MILATRAS does a little better in predicting transfers, being closer overall to the observed number of transfers. However, MILATRAS under-predicts trips with a single transfer, which are the majority of trips.

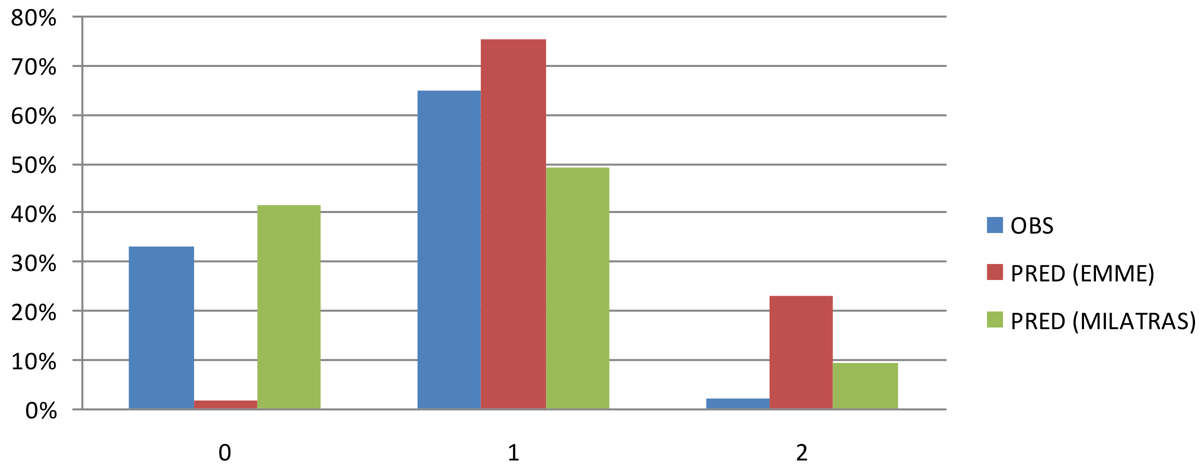

Figure 4.1: Histogram of Operator Transfers

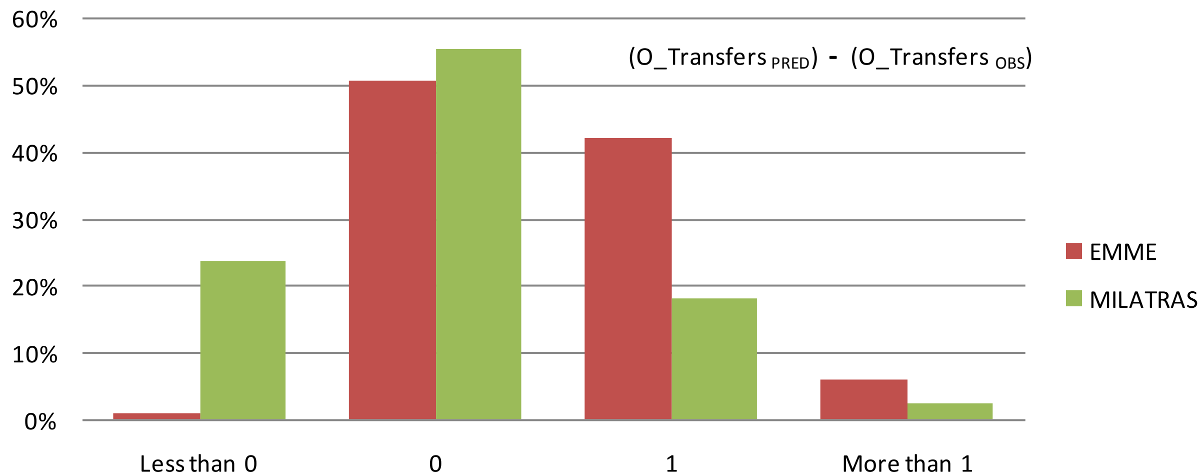

Figure 4.2: Histogram of Operator Transfer Differences

Figure 4.2 illustrates difference in predicted against observed operator transfers for the dataset; in this case the specific measure is ($\text{TRANSFERS}_{\text{PREDICTED}}$) - ($\text{TRANSFERS}_{\text{OBSERVED}}$). Both programs predict the correct number of transfers for a little more than half of the trips. EMME, however, over-predicts most of the rest, while MILATRAS over-predicts some and under-predicts others. This links well with Figure 4.1; EMME on average over-predicts operator transfers, while the over/under-predictions from MILATRAS 'cancel' each other out.

4.2: Route Transfers

Although total route transfers, defined as the number of transit lines ridden, is not strongly associated with fare-based decisions, they were analyzed in order to look for more general trends which might affect other, fare-based decisions. Figure 4.3 shows the histogram of number of route transfers for each trip, similar to Figure 4.1. From this figure, it can be seen that the EMME algorithm also over-predicts the number of route transfers, while MILATRAS

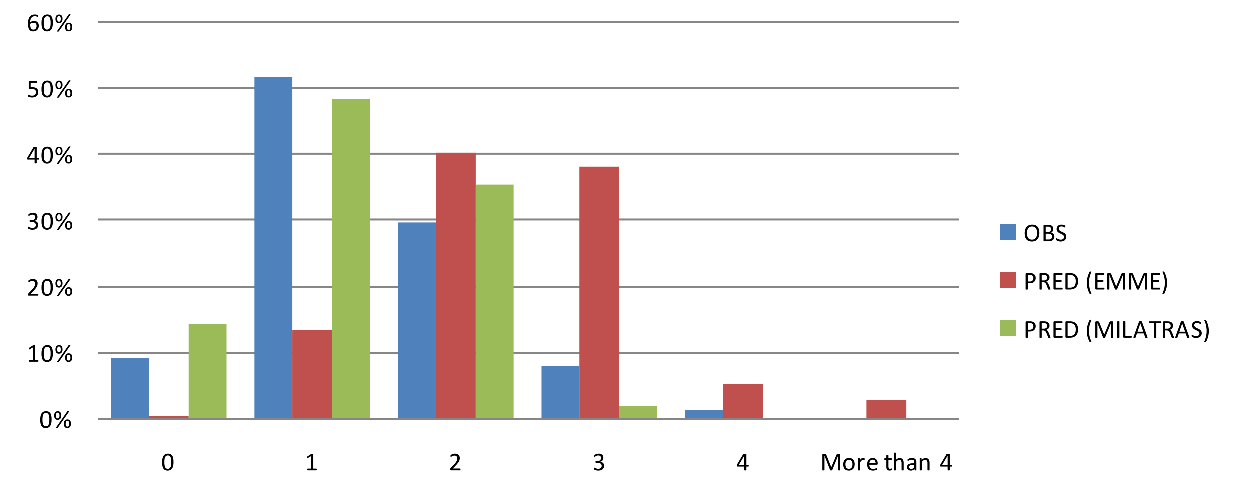

Figure 4.3: Route Transfer Histogram

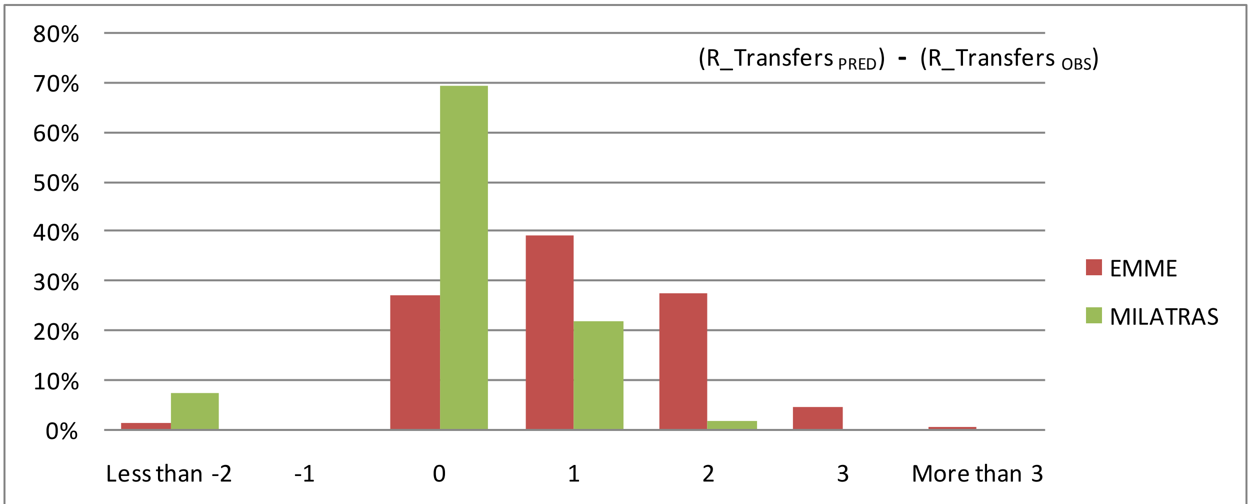

Figure 4.4: Difference in Route Transfers Histogram

matches the observed data much more closely. Figure 4.4, which is analogous to Figure 4.2, reinforces these trends. It seems that both assignment procedure tend to over-predict route transfers to some extant; a detailed investigation of this is outside the scope of this thesis paper.

4.3: Transfers by Operator

Lastly, specific operator-to-operator transfers were analyzed. Figure 4.5 presents the results of this analysis; it is presented using absolute values instead of percentages because the total number of transfers differs for each model. The most significant aspect of this chart is that it shows what transfer types are under- or over-predicted. For EMME, it is clear that transfers to and from Mississauga Transit are the largest source of over-prediction; total transfers from Mississauga Transit are more than twice as numerous in EMME than in the observed data. Looking at the data from MILATRAS, the first significant observation is that approximately the same number of operator transfers has been recorded as the observed data. This fits well with

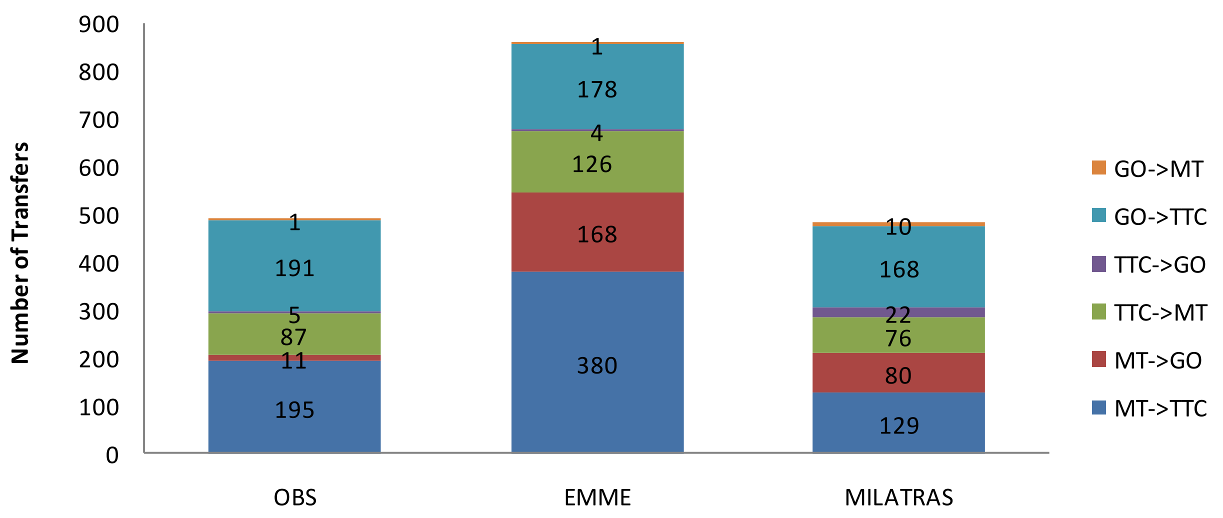

Figure 4.5: Operator Transfers by Transfer Type

earlier observations about how accurately MILATRAS models number of transfers. The second major observation is that MILATRAS slightly over-predicts transfers to GO Transit, although in the case of GO to MT and TTC to GO there are too few records to suggest a definitive trend.

Additional results can be found in Appendix B.

5.0: CONCLUSIONS AND RECOMMENDATIONS

In summary, this thesis compared two transit assignment programs, implemented in EMME and MILATRAS, and compared the their route choice algorithms to ascertain their accuracy in modelling fare-based travel behaviour. Individual trips crossing the Mississauga-Toronto boundary were modelled, and compared against actual route trip records in the Transportation Tomorrow Survey.

It was found that the EMME transit assignment algorithm significantly over-predicts the number of transfers between operators (with different fares), particularly between local (non-premium) operators. MILATRAS assignment results were, on average, more accurate; over-predictions of trips with more transfers were offset by under-predictions of trips with less transfers.

6.0: REFERENCES

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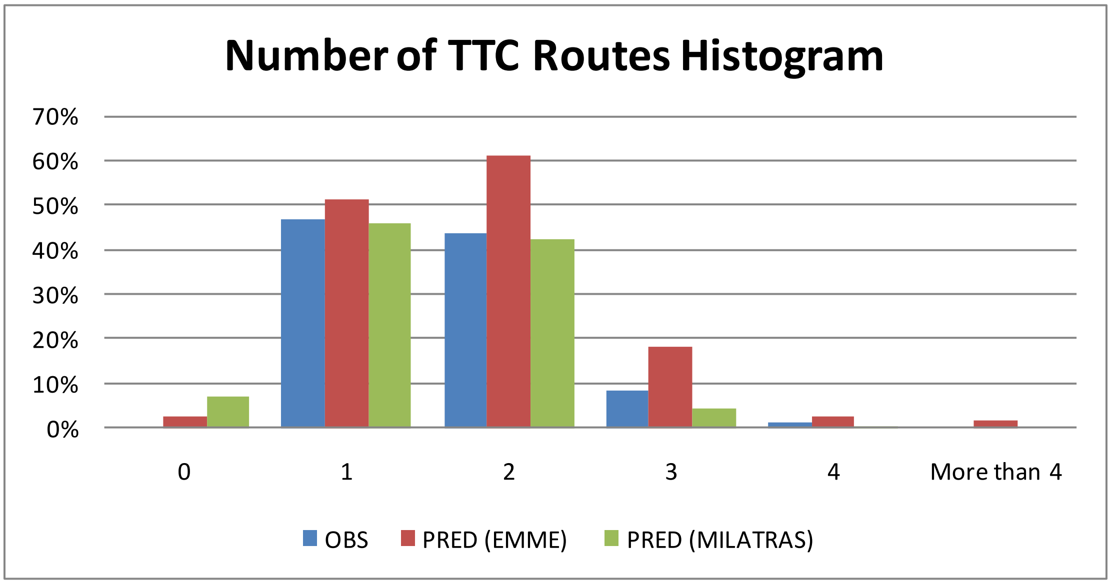
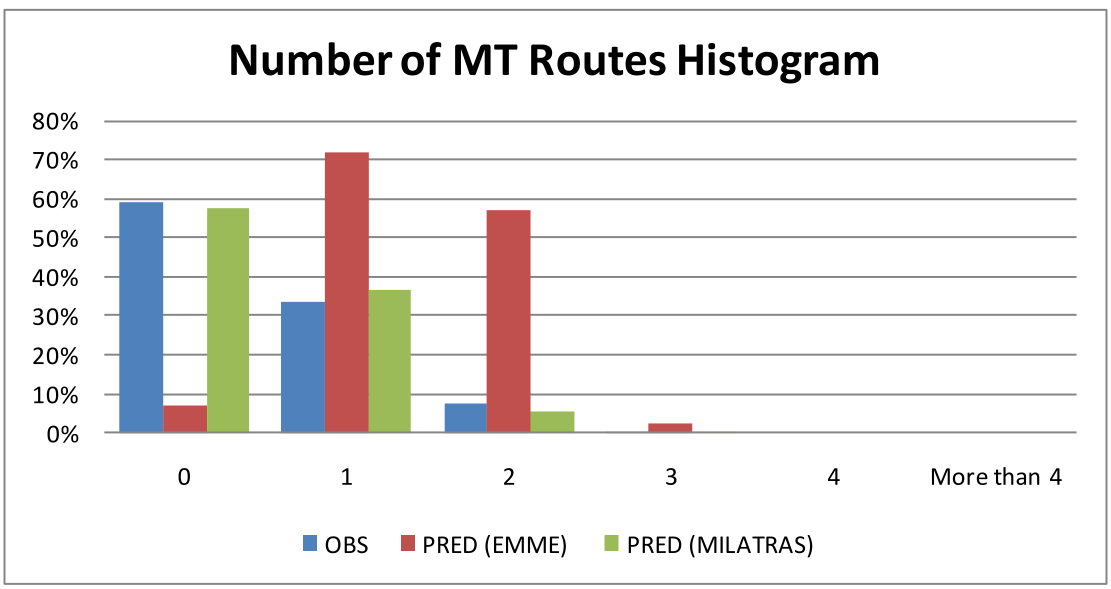
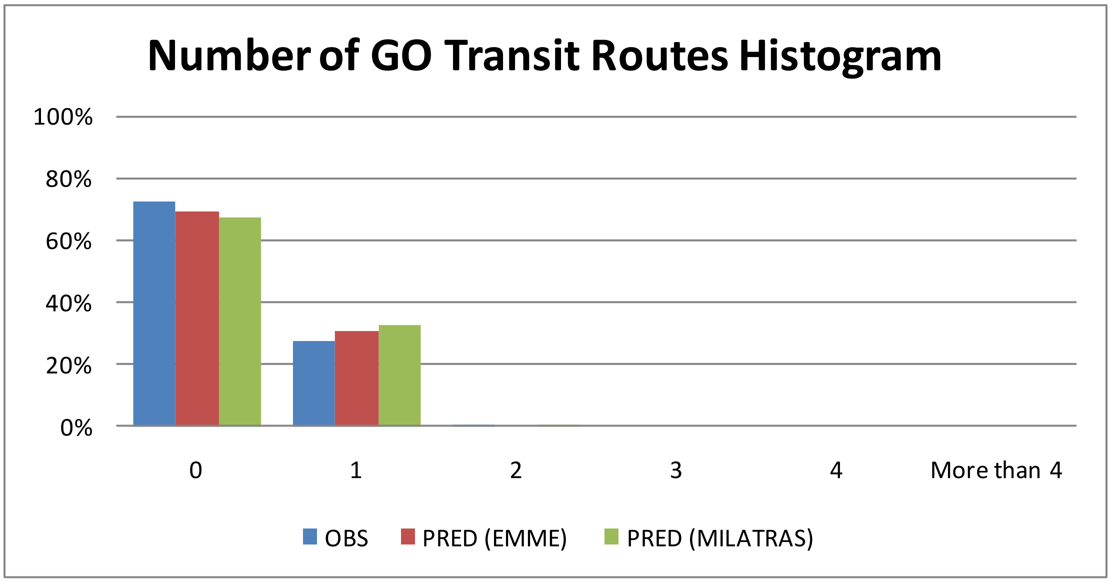
APPENDIX A: LIST OF MISSISSAUGA TRANSIT LINES MODELLED IN MILATRAS

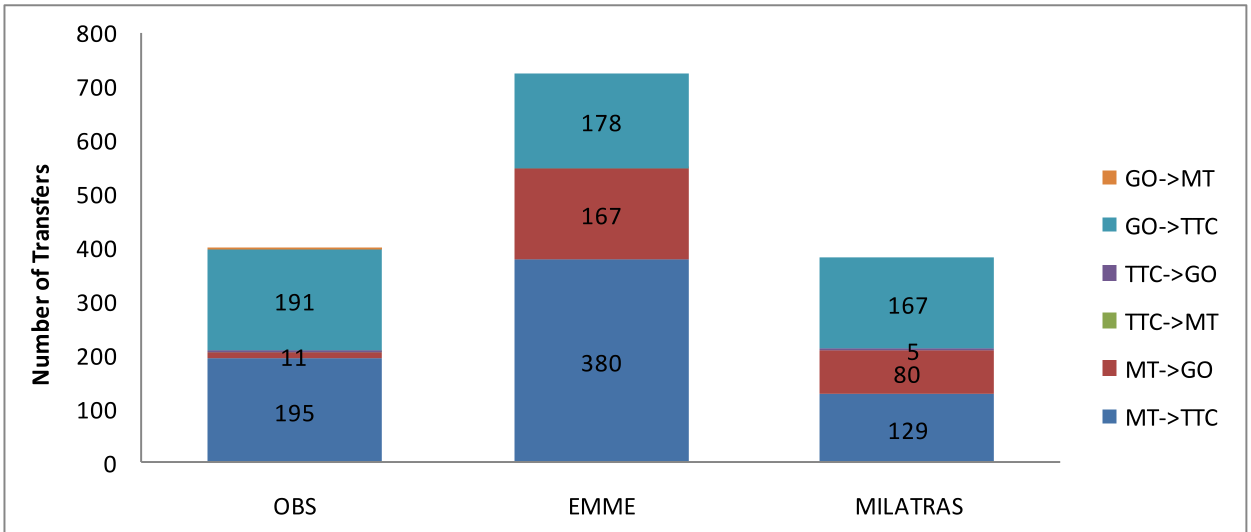
GIS ID	Description	TTS ID	EMME ID	MILATRAS ID
1A	Dundas East	MS01	PM001A	10010
1B	Dundas West	MS01	PM001A	10011
3A	Bloor East	MS03	PM003	10030
3B	Bloor West	MS03	PM003	10031
4A	Sherway Gardens East	MS04	PM004	10040
4B	Sherway Gardens West	MS04	PM004	10041
5A	Dixie North	MS05	PM005	10050
5B	Dixie South	MS05	PM005	10051
6A	Credit Woodlands-Westdale East	MS06	PM006	10060
6B	Credit Woodlands-Westdale West	MS06	PM006	10061
7A	Airport North	MS07	PM007	10070
7B	Airport South	MS07	PM007	10071
8A	Cawthra-Indian Road North	MS08	PM008	10080
8B	Cawthra-Indian Road South	MS08	PM008	10081
9A	Rathburn-Miller's Grove North	MS09	PM009	10090
9B	Rathburn-Miller's Grove South	MS09	PM009	10091
10A	Bristol-Britannia North	MS10	PM010	10100
10B	Bristol-Britannia South	MS10	PM010	10101
11A	Westwood South	MS11	PM011	10110
11B	Westwood North	MS11	PM011	10111
12A	Rexdale East	MS12	PM012	10120
12B	Rexdale West	MS12	PM012	10121
13A	Glen Erin North	MS13	PM013	10130
13B	Glen Erin South	MS13	PM013	10131
16A	Malton Loop South	MS16	PM016	10160
16B	Malton Loop North	MS16	PM016	10161
17A	Timberlea North	MS17	PM017	10170
17B	Timberlea South	MS17	PM017	10171
18A	Northwest-Explorer North	MS18	PM018	10180
18B	Northwest-Explorer South	MS18	PM018	10181
19A	Hurontario North	MS19	PM019	10190
19B	Hurontario South	MS19	PM019	10191
20A	Rathburn East	MS20	PM020	10200
20B	Rathburn West	MS20	PM020	10201
22A	Finch East	MS22	PM022	10220
22B	Finch West	MS22	PM022	10221
23A	Lakeshore East	MS23	PM023	10230
23B	Lakeshore West	MS23	PM023	10231
25A	Traders Loop Clockwise	MS25	PM025	10250
26A	Burnhamthorpe East	MS26	PM026A	10260
26B	Burnhamthorpe West	MS26	PM026A	10261
27A	Matheson North	MS27	PM027	10270
27B	Matheson South	MS27	PM027	10271
28A	Confederation North	MS28	PM028	10280
28B	Confederation South	MS28	PM028	10281
34A	Credit Valley East	MS34	PM034	10340
34B	Credit Valley West	MS34	PM034	10341
38A	Creditview North	MS38	PM038	10380
38B	Creditview South	MS38	PM038	10381
39A	Britannia East	MS39	PM039	10390
39B	Britannia West	MS39	PM039	10391
42A	Derry East	MS42	PM042	10420
42B	Derry West	MS42	PM042	10421
44A	Mississauga Road North	MS44	PM044	10440
44B	Mississauga Road South	MS44	PM044	10441
45C	45A Winston Churchill-Financial North	MS45	PM045	10450
45D	45A Winston Churchill-Financial South	MS45	PM045	10451
47A	Ridgeway Loop Clockwise	MS47	PM047	10470
48A	Erin Mills North	MS48	PM048	10480
48B	Erin Mills South	MS48	PM048	10481
49A	McDowell East	MS49	PM049	10490
49B	McDowell West	MS49	PM049	10491
51A	Tomken North	MS51	PM051	10510
51B	Tomken South	MS51	PM051	10511
53A	Kennedy North	MS53	PM053	10530
53B	Kennedy South	MS53	PM053	10531
57A	Courtneypark North	MS57	PM057	10570
57B	Courtneypark South	MS57	PM057	10571
61A	Mavis North	MS61	PM061	10610
61B	Mavis South	MS61	PM061	10611
65A	Barondale Clockwise	MS65	PM065	10650
67A	Cantay	MS67	PM067	10670
70A	Keaton East	MS70	PM070	10700
70B	Keaton West	MS70	PM070	10701
74A	City Centre Shuttle	MS88	PM200E	10740
82A	Financial North	MS82	PM082	10820
82B	Financial South	MS82	PM082	10821

APPENDIX B: ADDITIONAL RESULTS

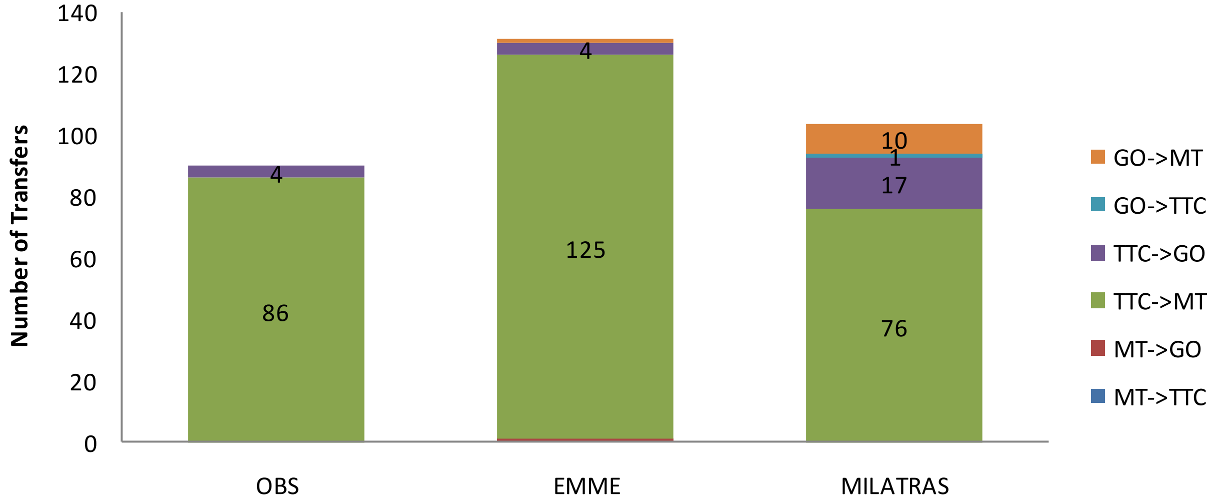








Operator Transfers by Transfer Type: Mississauga to Toronto Trips ONLY



Operator Transfers by Transfer Type: Toronto to Mississauga Trips ONLY