travel modelling group

Transit Assignment Calibration Report

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1. Introduction

In order to support the development of GTAModel V4.2, a calibration of the network assignment model has been done for the 2016 bus-capacity updated network. This report summarizes the procedure of evaluating different parameter structures and how the final parameter values were calibrated. Major changes as compared to GTAModel V4.1.1 includes the following:

- Various boarding penalties by operator group, instead of one uniform value for all local transit.
- A re-structure of Transit Time Functions (TTFs), where Exclusive-Right-of-Way (EROW) buses are separated from EROW Streetcars/LRTs.
- Segment-specific EROW speeds (@erow_speed) are updated based on GTFS and AM-peak travel time data, instead of zero everywhere.

2. Bus-capacity updated network

In July 2020, a line-by-line check was done by a summer student, Peter Lai, for the 2016 base network. The original 2016 network had followed the vehicle specifications used in the 2011 network, which was mainly based on GTFS data. Therefore, to improve the network, a thorough investigation was done by comparing the GTFS data with the route and vehicle information from the Canadian Public Transit Discussion Board (CPTDB) Wiki to update the bus capacities on each transit route.

The changes are summarized in Table 1. In general, the bus capacities have been increased for most transit lines in the network. For example, many local transit routes had employed 40ft buses instead of 30ft buses in 2016, and a few routes had even switched to articulated buses. Furthermore, when a transit route uses a mix of two vehicle types, the dominant one or more frequent one has been assigned to the route.

Table 1 Summary of Bus Capacity Changes

Agency	Emme Prefix	Total No. of Routes	No. of Routes Updated	30ft Bus -> 40ft Bus	30ft Bus -> Artic. Bus	40ft Bus -> Artic. Bus	Coach Bus -> Double-decker
Brampton	**B**	202	202	191	11	-	-
Durham	**D**	202	189	189	-	-	-
GO Bus	**GB**	231	76	-	-	-	76
GO Train	**GT**	47	-	-	-	-	-
Burlington	**HB**	73	67	67	-	-	-
Milton	**HM**	26	20	20	-	-	-
Oakville	**HO**	90	84	84	-	-	-
MiWay	**M**	266	226	169	57	-	-
TTC Surface	**T**	919	17	-	-	17	-
TTC Subway	**TS**	36	-	-	-	-	-
Hamilton	**W**	126	118	87	31	-	-
YRT	**Y**	355	302	302	-	-	-
VIVA	**YV**	30	-	-	-	-	-
TOTAL		**2603**	**1301**	**1109**	**99**	**17**	**76**

3. Evaluation Criteria

The criteria used to evaluate all proposed scenarios are the following, as compared to the modelled values. The comparisons were done for AM and PM peak periods separately unless otherwise specified.

1) Total boardings by operators of TTS observed.
2) Total inter-/intra-operator transfers of TTS observed.
3) Subway ridership by direction for "critical" points.
4) Total boardings of each transit line in the GTHA.
5) Local transit ridership by routes and by operators.
6) GO Transit ridership by route (both trains and buses).
7) Passengers on/off at interchange subway stations.

Due to the limited space, this report only shows the comparison results of the first criterion (i.e., total boardings by operators of TTS observed vs. modelled), which is also considered to be the most important one.

In addition, a fitness value is used to evaluate the convergence and is calculated using a RMSE method with the following formulas:

$$Fitness = 0.49AM + 0.33PM$$

Where,

$$AM\ (or\ PM) = \left[\frac{Sum(Error)}{Count(Error)}\right]^{0.5}$$

$$Error = (Observed - Modelled)^2$$

The error was calculated for each individual transit line.

4. Network Assignment Parameters

There are five types of network assignment parameters that need to be calibrated, including Fare Perception, Wait Time Perception, Walk Time Perception, Boarding Penalty (BP), and Transit Time Function (TTF). Although the calibration considers AM and PM peak periods separately, the parameters are set to be the same for both periods (e.g., the fare perception is the same for both AM and PM assignments).

The structure of fare perception, wait time perception, and walk time perceptions remains the same as GTAModel V4.1.1, where fare and wait time perceptions are uniform values within the network and walk time perceptions are different for each type of link: PD1, Toronto roads, Toronto centroid connectors, Non-Toronto roads, Non-Toronto centroid connectors, subway platforms.

This section will discuss the experiments of the other two network assignment parameters (i.e., boarding penalties and transit time functions) as well as the calibration of the best scenario.

4.1 Boarding Penalties

In GTAModel V4.1.1, all the transit lines share the same boarding penalty value, except for GO buses. To achieve better performance for V4.2, various boarding penalty scenarios were tested as shown in Table 2. For instance, in the 3BP scenario, three boarding penalty values were set, one for all local transit, one for TTC buses/streetcars, and another for GO buses.

Table 2 Boarding Penalty (BP) Scenarios

	3BP	Agency Specific	3BP-Hamilton	3BP-HamiltonMiWay	3BP-HamiltonMiwayViva	5BP
Brampton	1	Different boarding penalty for each operator	1	1	1	1
Durham	1		1	1	1	1
GoBus	2		2	2	2	2
Halton	1		1	1	1	1
Hamilton	1		3	3	3	4
MiWay	1		1	3	3	3
Streetcar	3		3	3	3	3
TTCbus	3		3	3	3	3
Viva	1		1	1	3	5
YRT	1		1	1	1	5

Since the boarding penalty value is likely to be "averaged" when grouping multiple operators together, an agency-specific BP scenario was tested to illustrate the extreme values for each transit operator. For all scenarios, the boarding penalties for GO Trains and Subway are fixed to zero.

4.2 TTFs and EROW Speeds

The re-structure of Transit Time Functions (TTFs) is as shown in Table 3. For V4.2, the EROW buses are separated from EROW Streetcars/LRTs considering the impact of different technologies on the congestion exponents. Additionally, the TTFs with the same type of vehicle are now sharing the same congestion exponent value (i.e., one value for TTF 2 and 3 and another value for TTF 4 and 6).

Table 3 TTF Definitions of GTAModel V4.1.1 vs V4.2

TTF	V4.1.1	V4.2
1	Heavy Rail	Heavy Rail
2	EROW Buses/LRT/Streetcar	EROW LRT/Streetcar
3	Streetcars	Streetcars
4	Buses	Buses
5	GO Buses	GO Buses
6	Not Defined	EROW Buses

During the test with TTF re-structure, it is found that the segment-specific EROW speeds (@erow_speed) are zero everywhere in the V4.1.1 network. By default, the global EROW speeds, as shown in Table 4, would be assigned to the segments that have EROW for transit and do not have @erow_speed defined.

Either a global EROW speed or @erow_speed has to be defined for any EROW segments in order for the Surface Transit Speed Updating (STSU) module to work properly.

Table 4 EROW Speeds (km/h) of GTAModel V4.1.1 vs V4.2

Vehicle	V4.1.1	V4.2
Local bus	35	35
GO bus	80	80
Streetcar	30	20

To improve the model performance for EROW transit, efforts were made to generate the EROW speeds (@erow_speed) for all the segments with a TTF value of 2 or 6 (i.e., EROW buses/LRTs/Streetcars). The main data source is GTFS feeds, with the help of AM-peak auto travel time data.

Generally, the GTFS stops were matched with Emme transit nodes in order to use the GTFS stop times. Since GTFS stops are not perfectly aligned with the transit nodes, many manual look-ups were required. If a GTFS segment is the same as the Emme transit segment, the vehicle speed on such segment is simply calculated by the segment length and the GTFS stop times. However, in many cases, one GTFS segment covers multiple Emme segments, including both Shared- and Exclusive-ROW roads. In such a case, the AM-peak auto travel times on the Shared-ROW are used to calculate the difference. To limit the calculation bias, a lower limit of 5km/h was set for all EROW segments.

Although the global EROW speeds are no longer needed at this point, they are kept in the V4.2 model for consistency and for future modelling needs in case a segment-specific speed is not available.

4.3 Calibration

All proposed scenarios were evaluated using the criteria described in Section 3. Due to the limited space, only the results of the most important criterion, the total boardings by operators, are shown in Table 5. For each scenario, a model run produces about 100 generations depending on the execution time. Since a model run could take up to 5 days, early termination may be imposed if no more improvement in fitness has been achieved.

As seen in the table, the best two generations of each scenario are tested in network assignments and the results are used to compare with other scenarios. When selecting the best scenario, both AM and PM differences were taken into consideration. It is shown that 5BP scenario has a relatively smaller fitness value as well as modelling the boardings closer to TTS observed, as compared to the other five scenarios. Other evaluation criteria that are not shown in this report, such as transfers between agencies, also support this finding.

Based on the recommended 5BP scenario, an additional scenario was tested with the updated segment-specific EROW speeds (@erow_speed) and the TTF re-structure, which is labelled as 5BP* in Table 5. As expected, the 5BP* scenario outperforms all other scenarios and thus is suggested for further use.

Table 5 Difference (%) of TTS Observed and Modelled Boardings for BP Scenarios

	Group	3BP		Agency Specific		3BP - Hamilton		3BP - Hamilton MiWay		3BP - Hamilton MiWayViva		5BP		5BP*	
	Generation	74	98	90	61	49	71	35	86	108	113	79	96	116	100
	Fitness	471	470	446	449	454	455	451	453	453	454	454	455	444	444
AM	Brampton	-9.3	4.6	-2.3	-7.8	-15.0	-3.6	-7.1	-8.9	7.0	-0.3	-13.7	-9.6	-13.6	-7.3
	Durham	-7.3	14.2	11.2	15.0	-12.5	-1.6	0.6	-1.3	7.7	-1.0	-8.6	-2.4	-4.0	-10.1
	GO Bus	-30.1	-22.9	-44.5	-44.4	-31.6	-29.2	-27.8	-24.1	-36.7	-34.8	-41.5	-40.2	-29.6	-37.6
	GO Train	-1.4	-0.8	2.8	1.6	0.0	-0.7	3.4	0.5	1.0	0.5	3.4	2.8	2.9	2.7
	Halton	14.9	37.6	39.8	39.7	8.9	20.4	15.5	16.6	27.1	19.7	11.8	14.8	12.2	11.6
	Hamilton	-6.6	8.6	-10.9	-5.4	-10.9	-7.8	-4.6	-4.4	-7.2	-11.8	-11.8	-9.0	-1.6	-10.3
	MiWay	7.8	22.0	-4.9	-7.6	-1.1	11.7	2.0	3.2	-2.8	-8.2	-11.3	-6.1	-4.5	-20.2
	Streetcar	32.8	28.0	8.7	2.0	31.0	32.5	26.4	31.3	30.8	29.5	12.8	10.5	1.8	3.8
	Subway	-3.1	-4.4	0.3	0.0	-3.8	-3.5	-2.3	-3.1	-4.3	-3.9	0.1	0.3	0.8	0.3
	TTC Bus	-4.1	-4.6	-9.9	-9.7	-4.2	-4.1	-2.6	-3.8	-3.5	-4.6	-8.8	-10.4	-10.7	-9.0
	VIVA	-7.4	-21.8	18.9	-6.6	-14.1	-9.4	-24.9	-24.2	-37.5	-34.2	-16.2	-21.8	-20.8	-16.6
	YRT	-6.7	27.1	-26.7	-17.7	-15.4	0.5	3.3	1.3	22.0	9.4	2.6	2.3	18.6	-7.3
PM	Brampton	-3.1	7.4	6.8	-1.3	-6.8	2.8	-0.5	-1.4	11.8	8.1	-6.0	-1.8	-5.3	2.2
	Durham	-6.7	11.0	11.5	14.2	-11.5	-1.3	0.2	-0.5	8.9	0.5	-7.5	-2.5	-4.1	-8.1
	GO Bus	-11.2	-3.0	-33.2	-32.4	-15.0	-10.4	-10.8	-8.9	-24.0	-19.3	-29.0	-26.5	-13.4	-23.5
	GO Train	-8.3	-6.8	-2.4	-3.6	-7.0	-8.0	-2.2	-5.4	-4.7	-5.6	-1.0	-1.8	-2.1	-2.1
	Halton	18.8	36.0	39.8	39.2	12.3	23.8	21.8	21.7	29.1	23.6	14.7	20.7	19.5	14.5
	Hamilton	1.6	15.1	-5.1	1.8	-4.4	-0.4	2.6	2.6	-0.7	-5.7	-5.8	-3.9	6.0	-3.6
	MiWay	15.3	28.7	1.7	-1.6	6.2	18.9	6.9	7.9	2.7	-0.9	-4.1	-0.3	0.7	-13.4
	Streetcar	43.8	37.0	8.3	0.8	42.0	41.7	33.4	43.3	39.1	39.3	14.2	11.4	2.8	3.8
	Subway	-6.6	-8.7	-1.5	-2.1	-8.9	-8.4	-6.5	-7.7	-8.8	-8.5	-1.9	-1.9	-1.8	-2.1
	TTC Bus	-3.6	-3.9	-9.4	-9.2	-2.7	-3.1	-1.9	-3.1	-1.7	-2.7	-7.9	-9.7	-10.3	-8.2
	VIVA	-1.4	-14.9	27.9	-2.1	-7.6	-2.5	-17.2	-17.2	-31.5	-28.7	-9.6	-15.7	-12.4	-9.2
	YRT	7.2	37.1	-17.5	-8.3	-2.9	14.6	12.9	10.8	34.5	22.1	13.4	9.0	28.2	3.6

Two additional tests were done for the 5BP* scenario to see if the model performance could be further improved. The first test was to set different In-vehicle Time Perceptions for premium buses (i.e., GO Buses, VIVA) and regular buses, which previously equals one for all transit. The second test was to set Transfer Boarding Penalties different from the Initial Boarding Penalties using the same grouping structure, which previously have the same values as the initial penalties by default. However, neither of the tests indicates better performance, and the original 5BP* scenario still provides the best modelled volumes and the best fitness. The results of the boarding comparison are shown in Table 6.

Table 6 Difference (%) of TTS Observed and Modelled Boardings for 5BP Tests

	Group	**5BP***		**5BP* with IV Perception**		**5BP* with Transfer Penalty**	
	Generation	116	100	77	88	61	55
	Fitness	444.0377	444.2174	470.1512	476.9331	448.874	450.5493
AM	Brampton	-13.6	-7.3	15.6	24.3	-25.3	-26.4
	Durham	-4.0	-10.1	10.7	19.5	-17.4	-19.7
	GO Bus	-29.6	-37.6	-17.1	-21.8	-34.1	-25.2
	GO Train	2.9	2.7	4.5	4.5	4.3	3.9
	Halton	12.2	11.6	34.4	43.8	-7.4	-7.6
	Hamilton	-1.6	-10.3	15.3	24.5	-0.9	-14.6
	MiWay	-4.5	-20.2	-10.7	-5.6	-16.6	-17.7
	Streetcar	1.8	3.8	1.3	-1.8	-2.8	-2.2
	Subway	0.8	0.3	0.1	0.4	0.9	0.9
	TTC Bus	-10.7	-9.0	-12.2	-12.7	-11.5	-11.9
	VIVA	-20.8	-16.6	-26.4	-35.2	-20.5	-22.1
	YRT	18.6	-7.3	0.2	5.1	-16.9	-18.0
PM	Brampton	-5.3	2.2	18.6	28.4	-18.6	-20.1
	Durham	-4.1	-8.1	9.5	16.3	-21.4	-23.5
	GO Bus	-13.4	-23.5	7.3	-4.2	-18.2	-6.5
	GO Train	-2.1	-2.1	-1.0	-1.1	-1.1	-1.0
	Halton	19.5	14.5	33.1	41.6	-6.7	-8.2
	Hamilton	6.0	-3.6	23.0	30.9	7.4	-8.4
	MiWay	0.7	-13.4	-4.6	-1.0	-10.4	-11.1
	Streetcar	2.8	3.8	3.1	-0.3	-2.2	-1.4
	Subway	-1.8	-2.1	-2.8	-2.6	-1.7	-1.8
	TTC Bus	-10.3	-8.2	-11.4	-11.7	-10.9	-11.3
	VIVA	-12.4	-9.2	-17.0	-27.0	-13.7	-15.5
	YRT	28.2	3.6	11.7	13.7	-7.5	-7.8

Once the 5BP* scenario is selected as the best to use, a further calibration was done for its Generation 116 by altering the boarding penalty values. The calibration method involves four runs in total.

In the first run, 100 scenarios were randomly picked with the boarding penalty ranged from X-3 to X+3, where X is the boarding penalty value from the original 5BP* scenario. For instance, the boarding penalty of Brampton Transit is 10.53905 in Generation 116, so the possible penalty value is between 7 and 14. An examination was then performed for the AM and PM modelled boardings of the 100 scenarios, and the top 25% combinations that have the best estimates were filtered out.

Based on the best 25% combinations, the most frequent boarding penalty values were selected for the second run, which consists of about 430 scenarios. By repeating the same procedure, the third run has approximately 240 scenarios. By reviewing the results of the third run, a clear trend was observed and 6 scenarios were proposed for the fourth run, which is the final run. The summary of the 6 scenarios is shown in Table 7.

In general, most of the boarding penalties are very similar to the values in Generation 116, except for York Transit and GO Buses. It is found that a better estimate of boardings has been achieved when the boarding penalties of YRT and VIVA buses increased to 9, which is the same as the Suburban group. On the other hand, the estimate of boardings is better if GO Bus boarding penalty decreases to 4.5.

As comparing the modelled results of boardings and transfers, *Scenario 2* outperforms the rest and is thus recommended for the final model use.

Table 7 Calibration of Generation 116

	Gen 116	**Scen 1**	**Scen 2**	**Scen 3**	**Scen 4**	**Scen 5**	**Scen 6**
Brampton	10.53905	9	9	9	9	9	9
Durham	10.53905	9	9	9	9	9	9
Halton	10.53905	9	9	9	9	9	9
Hamilton	6.141904	6	6	6.5	6.5	7	7
MiWay	12.67913	11.5	11.5	11.5	11.5	11.5	11.5
YRT	5.892951	8.5	9	8.5	9	8.5	9
VIVA	5.892951	8.5	9	8.5	9	8.5	9
Streetcar	12.67913	11.5	11.5	11.5	11.5	11.5	11.5
TTC Bus	12.67913	11.5	11.5	11.5	11.5	11.5	11.5
GO Bus	7.615213	4.5	4.5	4.5	4.5	4.5	4.5

5. Final Results

The network assignment parameters recommended for GTAModel V4.2 are summarized in Table 8. As compared to V4.1.1, wait time perception has decreased while the fare and walk time perceptions have increased. The boarding penalties have largely increased for most transit operators, which is considered as a combined result of the EROW speeds updating, TTF re-structure, and wait time perception increase. With regard to the TTF congestion exponents, the value of TTF2 decreases as the EROW buses have been separated from it. It is noticed that Shared-ROW streetcars (TTF3) also has the value decreased since it is forced to share the same value with EROW streetcars (TTF2). In contrast, the value of Shared-ROW buses (TTF4) increases when grouping with EROW buses (TTF6).

Table 8 Network Assignment Parameters for GTAModel V4.2 vs. V4.1.1

Parameter		**V4.1.1**	**V4.2**
Wait Time Perception		3.254213	2.742223
Fare Perception		14	20.92402
Walk Perceptions	PD1	1.334279	1.955037
	Toronto	1.305652	1.991714
	Non-Toronto	1.280929	1.671664
	Toronto Centroid Connectors	2.622789	3.967743
	Non-Toronto Centroid Connectors	3.793802	1.313519
	Subway	1	1.674086
Boarding Penalties	Brampton	5.5	9
	Durham	5.5	9
	Halton	5.5	9
	YRT	5.5	9
	VIVA	5.5	9
	MiWay	5.5	11.5
	Streetcar	5.5	11.5
	TTC Bus	5.5	11.5
	Hamilton	5.5	6
	GO Bus	3.5	4.5
TTF Congestion Exponent	TTF 1	5.972385	5.208812
	TTF 2	4.047056	2.523986
	TTF 3	4.091312	2.523986
	TTF 4	4.937087	6.944359
	TTF 5	6.439797	7.903756
	TTF 6	-	6.944359

A network assignment was done with the new parameters, and the estimated boardings by operators are as shown in Table 9. The difference between the observed and modelled boardings are less than 10% or even 5% for most of the transit operators. Some significant differences are noticed for GO buses, Halton, and VIVA. During the AM peak period, the modelled boardings on GO buses is 21% less than the TTS record, whereas the difference in the PM peak period is only 1%. As for Halton transit, the modelled total boardings is higher than the TTS observed by 13% in AM and 20% in PM, indicating that Halton transit lines in the model have been more attractive than expected. In contrast, VIVA buses have been less attractive where the modelled boardings are 30% (or 21%) less than the observed in the AM (or PM) period. Nonetheless, this final set of network assignment parameters still produces the best estimates in consideration of all evaluations that have been done during the calibration.

Table 9 Total Boardings by Operators

	Group	Observed	Modelled	Difference	Difference (%)
AM	Brampton	27789.42	24936.26	-2853.16	-10%
	Durham	12823.72	12354.70	-469.02	-4%
	GO Bus	20099.99	15854.53	-4245.46	-21%
	GO Train	90522.63	92519.56	1996.93	2%
	Halton	6437.75	7293.67	855.92	13%
	Hamilton	21979.29	21667.00	-312.29	-1%
	MiWay	45273.95	43685.27	-1588.68	-4%
	Streetcar	60671.15	64425.59	3754.44	6%
	Subway	427734.86	426893.82	-841.04	0%
	TTC Bus	331291.18	303897.27	-27393.91	-8%
	VIVA	8795.26	6175.67	-2619.59	-30%
	YRT	20237.15	20970.88	733.73	4%
PM	Brampton	33452.41	32303.33	-1149.08	-3%
	Durham	16995.39	16544.16	-451.23	-3%
	GO Bus	23249.57	22978.36	-271.21	-1%
	GO Train	95641.48	92973.30	-2668.18	-3%
	Halton	9148.96	10962.59	1813.63	20%
	Hamilton	28610.89	30403.63	1792.74	6%
	MiWay	56064.82	56827.33	762.51	1%
	Streetcar	85453.59	92655.21	7201.62	8%
	Subway	544109.06	528590.20	-15518.86	-3%
	TTC Bus	420562.44	389548.96	-31013.48	-7%
	VIVA	11513.57	9039.17	-2474.40	-21%
	YRT	26232.14	29124.42	2892.28	11%