Seamless Integration of Traffic and Transit Assignment with Activity-Travel Scheduling in An Agent-Based Modelling Framework

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Abstract

A behaviorally sound activity-based travel demand model would enable a realistic analysis of emerging mobility options and their integration into the complex transportation system. Available regional travel demand models in the Greater Toronto and Hamilton Area (GTHA) use aggregate, static, and deterministic user equilibrium-based network models (e.g., the GTA and GGH models). No operational demand model is available of the entire GTHA's multimodal transportation network that can capture the network dynamics and agent-based network microsimulation.

This paper presents such a model. It is based on integrating an activity-based modelling framework named CUSTOM (Comprehensive Utility Maximizing Travel Options Modelling) with a network model named GTASim that was developed using a multi-agent-based transport simulation framework to cover the entire GTHA region.

The CUSTOM model considers a 24-hour modelling time frame for the activity-travel scheduling process. It is based on the random utility maximization theory and provides individuals' joint choice of activity type, location, departure time and mode. The mode choice component is implicitly history-dependent through the choice set formulation and thus, captures the most fundamental physical constraints (i.e., tour constraints). The CUSTOM framework generates preferred activity-travel plans for agents representing the demand of the urban transport system. The GTASim model executes the plans assigning travellers to the road and transit networks representing the supply. The outcome of the demand-supply interaction is the urban transport system's level of service (LOS). The LOS is then fed back to the scheduler, generating adjusted activity-travel plans. This feedback mechanism represents the reality that trip markers modify their behaviours considering scarce and sometimes costly transport network supply.

However, the GTASim and CUSTOM model is calibrated independently to the Transportation Tomorrow Survey 2016 household travel survey dataset, and the feedback loop is still missing. Moreover, the current GTASim cannot accurately account for the time-varying monetary cost of travel. Hence, this paper makes two substantial and noteworthy contributions. Firstly, the study extends GTASIM's capacity to account for the monetary cost of individual trips in the scoring of each trip leg (with a focus on transit fares). Then, developing the integrated framework which makes it transferable to any study context. The GTASim model with the new capability is further compared to the available EMME-based regional model.

Our adaptable and forward-thinking framework considers changing travel preferences and provides authorities with a powerful tool for meeting future transportation demands while ensuring safety and efficiency for all.

1. **Background**

As demand for transportation in cities grows, the need to accurately understand the impacts of transportation policy and infrastructure interventions becomes more critical and challenging to fulfill. Large metropolitan areas host intricate and complex multimodal transportation networks that serve diverse residents with different priorities and needs. As such, more valuable and high-quality transportation models should be able to capture the unique responses to various interventions by other residents and different groups of residents. The integration of the GTASim network model and Comprehensive Utility maximizing System of Travel Options Modelling (CUSTOM) framework by Mashrur, Lavoie, Wang and Habib[1] aims to provide this capability for the Greater Toronto and Hamilton Area (GTHA).

The GTHA is the largest population center in Canada, with 7.2 million people spread across 8,244 square kilometers. It comprises 30 different municipalities and six different regions and is one of the fastest-growing metropolitan areas in North America, with the population expected to reach 10 million people by 2041. The GTHA is served by 10 different local transit agencies operated by individual municipalities and an interregional transit agency operated directly by the Government of Ontario[2] [3].

Transportation models in the GTHA started with Static Traffic Assignment (STA) and four-stage demand models. Models incorporating STA are computationally efficient but have significant limitations. As it relates to this paper, the primary limitation is the inability to capture the impact of transportation interventions, whose impact is driven by the psychological and behavioural decision-making processes that define different transportation users. Examples of GTHA models of this type include early versions of the GTAModel, a four-stage-based model for morning peak demand developed with the EMME software[4], and the Greater Golden Horseshoe Model (GGHM), a four-stage model designed to forecast long-term transportation demand for the Greater Golden Horseshoe that has been used by transportation planners across the region[5].

The GTASim network model and CUSTOM framework present another evolution for transportation modelling in the GTHA that combines an Activity-Based Modelling (ABM) approach with Dynamic Traffic Assignment (DTA). The advantage of the DTA capability of the GTASim (assembled using MATSim) is the modelling of spatiotemporal fluctuations in demand that considers varying travel times throughout the day. Recent computing advancements have mainly overcome the traditional criticism of computationally expensive DTA models. In the GTHA Kamel et al. developed a joint traffic-transit DTA framework that simulates car and transit traffic for the City of Toronto using Aimsun[6]. ABM better encapsulates real-world behavior by focusing on individuals' daily activities and derived travel demand from the activities. This allows tour constraints to be more accurately applied and enforced, and interhousehold trip-making decisions are also considered. The CUSTOM framework for the GTHA is one example of ABM; it captures individuals' choice behaviour of activity type, location, time allocation, and travel modes in 24 hours scheduling period.

MATSim is based on the co-evolutionary principle where all agents in the model repeatedly optimize their daily activity schedule by varying departure times, modes, or destinations[8]. This optimization is based on the "scoring" of different schedules, known as plans, based mainly on the activity-related utility and travel-related disutility derived from the plan. MATSim repeatedly iterates through a process of simulating the plans of all agents through the network mobility simulation (mobsim), scoring the plans, and then innovating new plans before eventually outputting, among other items, the ideal plans for all agents and the overall network demand characteristics[8].

This paper aims to further the behavioural modelling capability of the integrated GTASim-CUSTOM framework. In particular, the paper extends the GTASIM's (and MATSim's) capacity to account for the monetary cost of individual trips in the scoring of each trip leg by the modelling of zone-based fare schemes like that used in the GTHA by GO Transit to approximate distance-based fares. This paper emphasizes the development process of the new capability. The capability was built using Java and plugs into the MATSim framework. This new capability will allow for more accurate testing of complex transportation policies. This work's next steps include further integrating the GTASim and CUSTOM framework to build the feedback loop necessary to simulate real-world trip-making behaviour. The complete integrated modelling framework will enable an improved understanding of transportation networks with tools sensitive to individuals' activity-travel choice behaviour.

2. Literature Review

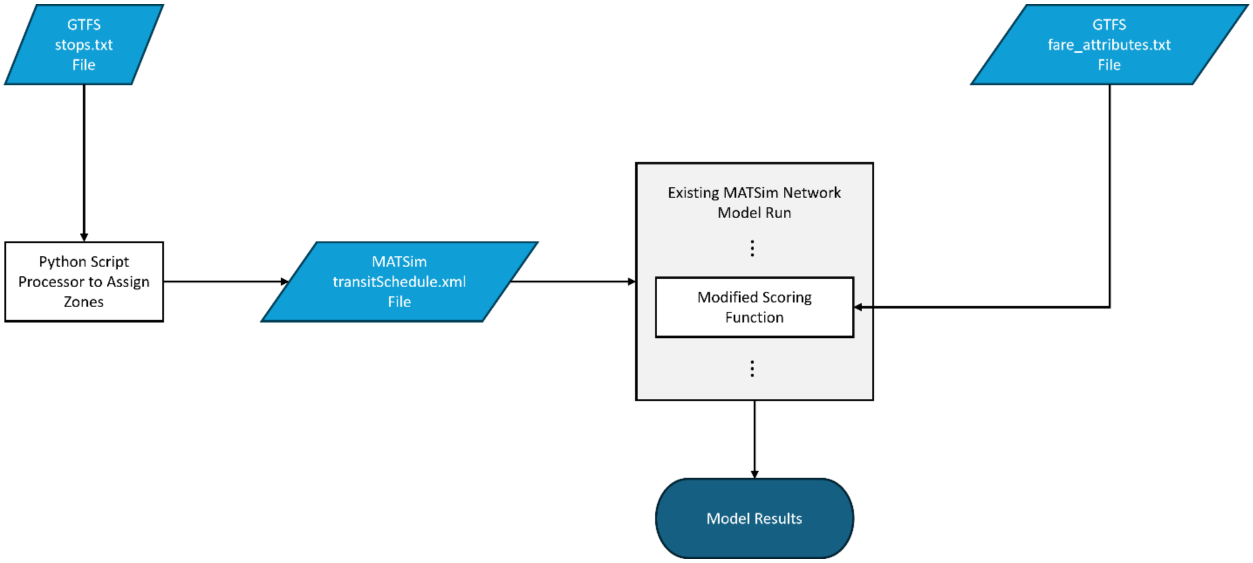
The most recent version of the GTAModel (Version 1.6) approximates GO fares as a per-km fare with an initial boarding fare[4]. The initial boarding fare is the lowest possible GO Transit fare (i.e. the cost to travel within a zone), and the per-km fare rate was estimated using linear regression[7]. The current GTASim model (Version 1) approximates GO fares as a per-km fare with an initial boarding fare organically incorporated as the alternative specific constant. The standard MATSim framework upon which the GTASim model was built allows transit fares to be modelled using the alternative specific constant, a monetary distance rate or a daily monetary constant[8].

No organic zone-based transit fare modelling capability exists in the standard MATSim framework[8]. Hong Kong's MTR rapid transit system uses a similar origin-destination (OD)-based fare structure to GO Transit, and a MATSim model developed for that city uses a custom transit assignment model that calculates fare incrementally per stop[9]. In other words, each link on the network incurs a fixed additional fare. No information could be found on the accuracy of this fare model, and it is also presumed to be too computationally expensive to implement for the GO Transit network. OD-based fare structures are known to exist in other cities with MATSim models. However, detailed information on the exact implementation of public transit fares proved challenging to find.

3. Methodology

A high-level overview of the zone-based fare functionality as it exists is as follows. The new capability requires raw GTFS files and edit access for the transit schedule XML file. The GTFS files are used to modify the transit schedule file and to retrieve the zone-based fare matrix. The modified transit schedule file with the rest of the MATSim network then runs the model, and a custom scoring function retrieves the fare for each trip from the fare file directly. MATSim's functionalities and outputs are otherwise unchanged, leading to results that are directly comparable to the existing model.

Figure 1. The general flow of zone-based fare capability



Data Collection

The new capability was tested using the GTFS fare_attributes.txt and stops.txt files from GO Transit's Developer Resources site[10]. The fare_ attributes.txt file contains the unique fares for each zone pair. The stops.txt file is used to assign GO Transit zones to individual stops in the transitSchedule.xml file to allow for the identification of the correct fare. A Python script needs to be run separately first to do this modification. The script leverages XML's extensible nature and uses the Attributable approach outlined in the MATSim book[8] to assign a new attribute called "GO transit fare" with type Integer to each GO Transit stop. The script goes through every stop in the transit schedule XML file and assigns zones based first on matching zone_ids and then matching coordinates. Any stops still not assigned a zone flagged for manual verification. This error-proofing was necessary given that the exact GTFS file used to build the GO Transit network in the GTASim model could not be identified.

Scope of Testing

The GTASim model and CUSTOM framework are built to model the entirety of the GTHA. However, only agents originating from the City of Toronto were tested to save run time during the development of the new zone-based capability. This resulted in 280,815 agents and 791,652 trips being modelled (2.82 trips per agent) in one day. The GTASim's base travel demand was derived directly from the trip diaries in the 2016 Transportation Tomorrow Survey (TTS), a regional household travel survey of 5% of the GTHA's population that is conducted every 5 years. The TTS collects anonymized trip diaries, with trip ODs recorded as one of the 2272 traffic zones in the GTHA. Random zone-specific zone coordinates were assigned to the ODs for use in the GTASim[1].

A corresponding adjustment to the capacity of the network was not applied during testing as a) travel originating from Toronto is presumed to comprise most demand for travel in the city and b) testing of the capability does not require the most accurate modelling possible. As well, in February 2024, the One Fare Program was implemented in the GTHA integrates transit fares across the different transit agencies in the region[11]. This program was not known at the time of development, and the current methodology does not easily fit with this development and is presumed to require significant modification to allow accurate modelling in MATSim of this new fare scheme.

Modified Scoring Function

Currently, each agent in a MATSim model possesses scoring parameters as a ScoringParameters object. These include activity-related parameters, such as the utility of performing a specific activity, that are stored as ActivityUtilityParameters and travel-related parameters, such as the disutility of travel time as well as monetary cost, that are stored as ModeUtilityParameters. At the beginning of each iteration, scoring parameters are used to evaluate each plan for each agent. Relevant for this study, the monetary cost for each plan is predefined for each mode as a constant in the config file. In further detail, at this point in scoring, the value it assigns to either dailyMonetaryConstant, representing the cost of using the mode as a single fixed value for the entire day, or monetaryDistanceRate, representing the per-km cost of using the mode, already has a known numerical value.

The new capability is built by creating subclasses of the relevant classes to allow for fetching of different daily monetary constants for each station pair. To utilize the capability, the daily monetary constant for the mode in question (for GTASim this is GO Transit) is instead set in the config file as the file path to the fare_attributes.txt GTFS file. When the mode parameters are read from the config file into the ModeParams class, the constructor attempts to type cast the value of the daily monetary constant into a double. Suppose it is successful (i.e. the daily monetary constant was set as a number in the config file). In that case, it is treated as a normal value and uses the existing MATSim functionality. However, if the type cast is unsuccessful, the string (that is presumably a file path) is stored under the string attribute fareAttributeFilePath.

When agents score their different plans, the ModeUtilityParameters class is created for each mode to retrieve the relevant travel-related parameters. To do this, an instance of the ModeParams class is passed to the ModeUtilityParameter Builder. The builder for this class has a method that is overloaded to also take in inputs for zone ids for GO Transit trips. This alternative method uses the zone ids and retrieves the corresponding fare directly from the fare_attributes.txt GTFS file that is specified by the fareAttributeFilePath attribute and multiplies by two to account for two trips in a day.

Figure 2. Simplified flow chart showing existing use of dailyMonetaryConstant in scoring of plans

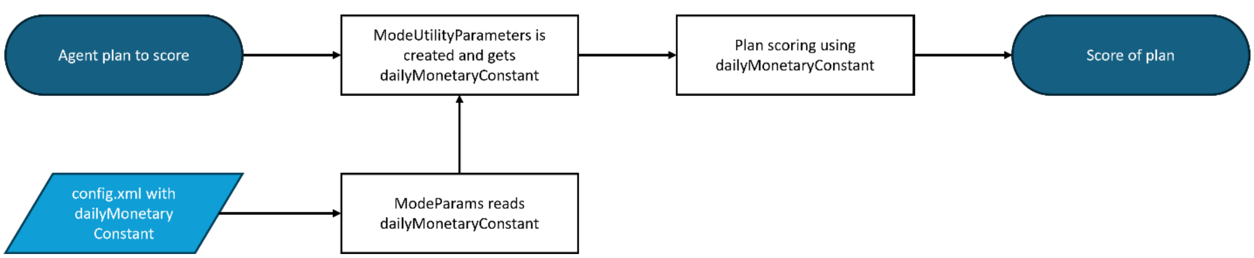
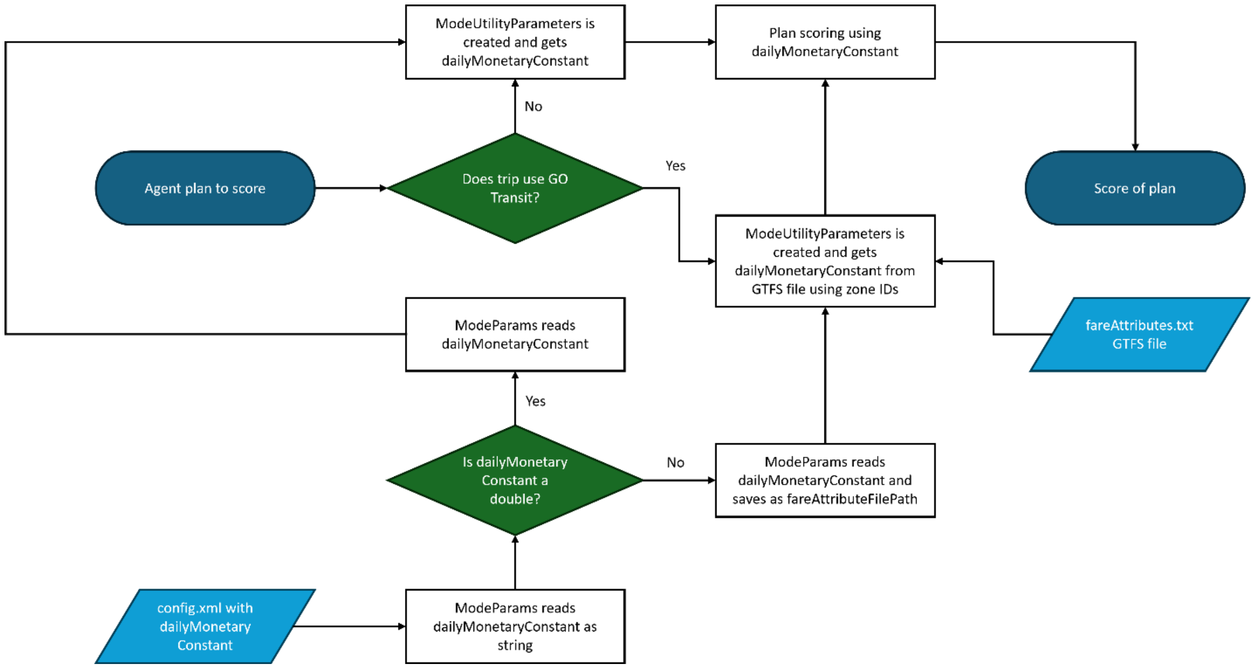


Figure 3. Simplified flow chart showing modified use of either constant dailyMonetaryConstant or zone-based fare as dailyMonetaryConstant in scoring of plans



4. Results and Discussion

Accuracy of Function

After testing, the new capability was found to be entirely accurate in identifying the correct fare for GO Transit for trips in the GTASim model. To verify the accuracy of the function, GO Transit fares were calculated for each of the possible trip OD pairs from the 2272 traffic zones in the GTHA separately using a Python script. These were then compared to fares outputted by MATSim for the finalized trips for all agents and were found to match.

Differences from Baseline GTASim Model

As shown in Figure 4 on the next page, as compared to the original GTASim results, implementation of the new zone-based fare modelling capability resulted in 58 agents switching to GO Transit and 216 agents switching away from GO Transit. This represents around 0.2% and 0.8% of the existing GO Transit ridership in the GTASim. This could suggest that the existing model's distance-based fare calculation is already reasonably good at approximating the actual GO Transit fare, or alternatively that GO Transit demand is relatively inelastic.

An interesting development is the higher proportion of users shifting away from GO Transit versus on to GO Transit. One possible reason may be due to the GTFS files used. The model was run with a more recent fare file from 2023 whereas the model was built using 2016 GTFS files. Fares in 2023 may be on average more expensive than in 2016, however this was not investigated. As well, the original GTASim model was noted for having a higher usage of GO Transit to Downtown Toronto, and the shift away may simply be a correction of this fact[1].

Figure 4. Changes in GO Transit ridership for GTASim with new capability

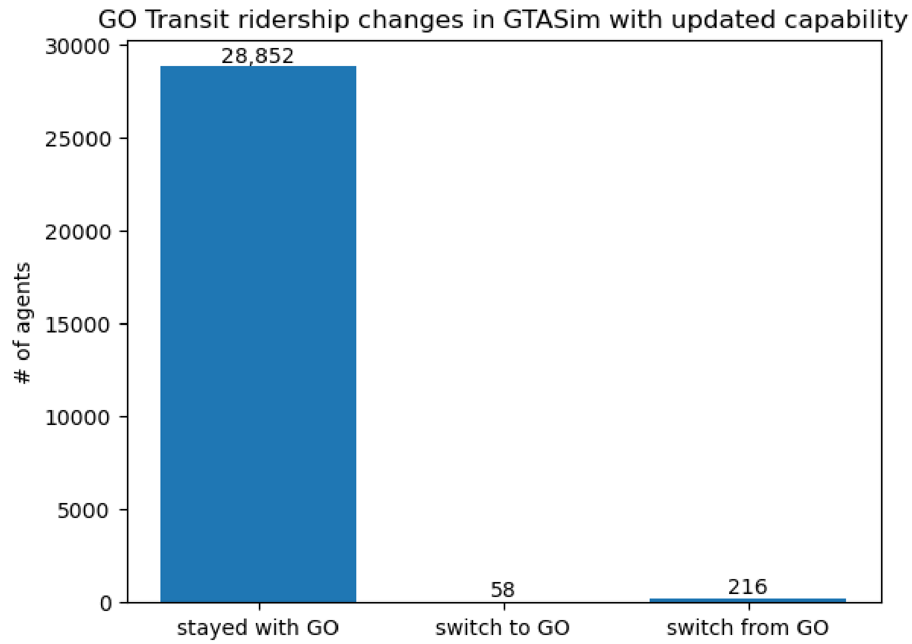


Figure 5 on the next page shows the spatial distribution of agents that changed to or from GO Transit in Toronto. The points represent the "home" locations of these agents. Clusters surrounding GO Transit rail stations can be observed, which is largely expected given that GO Transit's train service sees approximately 3 times as much ridership versus its bus service[12], and GO bus usage particularly within Toronto may be muted. Tighter clusters can be seen around stations in Scarborough along the Stouffville line and larger but more spread clusters can be seen in Etobicoke along the Lakeshore West, Milton and Kitchener lines. The tightness of the clusters may be indicative of the availability of alternatives, as locations with tighter clusters seem to have some correlation with areas that have a longer commute to Downtown Toronto were one to take local transit instead. Given that GO Transit's rail network is focused on servicing the downtown core, this seems a plausible theory.

Alternatively, the geographic distribution may indicate which GO Transit zones had fares poorly approximated by the previous distance-based scheme. Given the relatively small sample size of agents that switched modes and the uneven real-world distribution of GO Transit ridership, it was difficult to verify this. However, as was seen in Figure 1, outliers exist and may include GO Transit zones with significant ridership.

Figure 5. Geographic distribution of "home" locations for agents with changed trips

Differences from GTAModel (EMME-Based Regional Model)

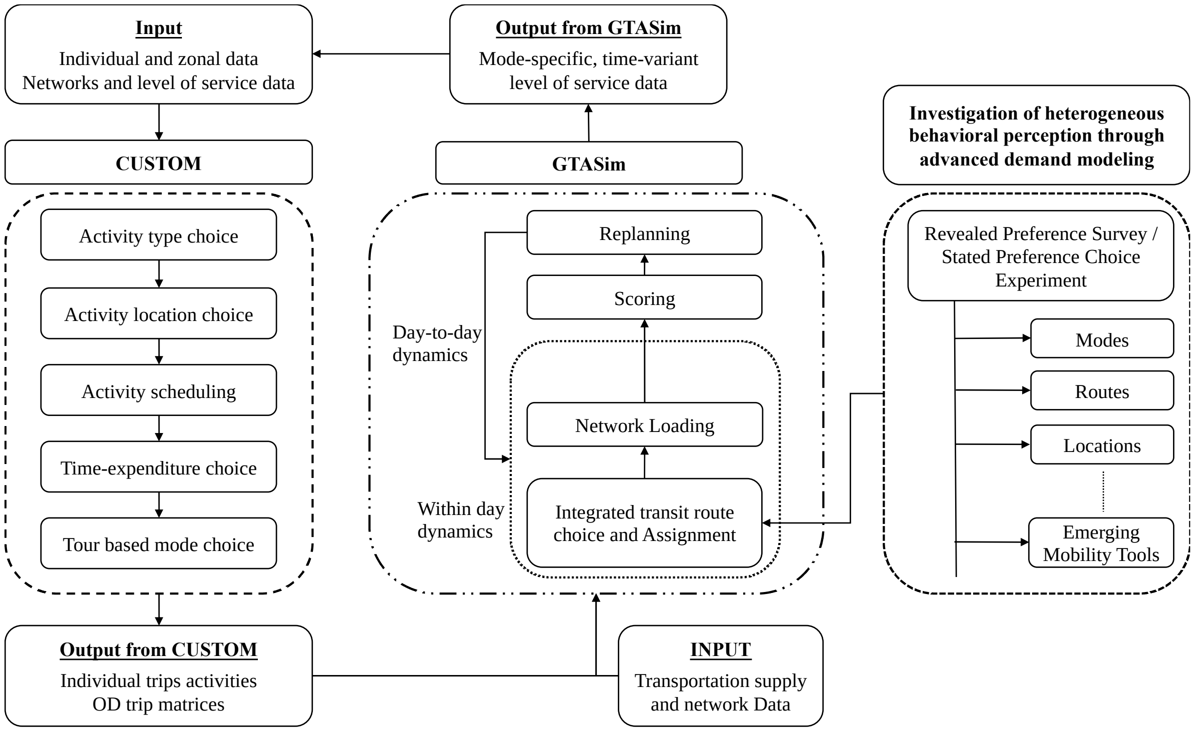
Due to difficulties in accessing the GTAModel, this section will be instead included in future work.

5. Further Steps

As cities and urban areas face increasing pressures and challenges in providing high-quality transportation, the need for models that accurately evaluate transportation interventions to ensure efficient usage of resources grows. This study develops another step towards a behaviourally-sound implementation of the GTASim-CUSTOM framework, providing a fully operational activity-based modelling framework. Next steps to be taken in developing the zone-based fare capability include creating an easily implemented version (a contrib in MATSim terms) and further optimizing the function. Currently, the capability modifies the source code directly, which is not feasible or recommended given that MATSim provides built-in extension points. The capability was also not written to be optimal for run time, and in particular, the constant need for I/O when scoring GO Transit trips could likely be resolved by simply importing the fare_attributes.txt file once and storing it somewhere in the controller.

Next steps in developing the integrated GTASim-CUSTOM framework include the development of the feedback loop that is currently not present. Figure 6 on the next page showcases the proposed completed integrated GTASim-CUSTOM framework with the feedback loop.

Figure 6. Integrated CUSTOM-GTASim Approach



Source: Travel Demand Modelling Group, Department of Civil Engineering, University of Toronto

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