Application of a Micro-Simulation Model for User Benefit Calculation for Transit Projects

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FTA has requirements to a travel demand model that is used to estimate user benefits (UB) of transit projects. These requirements are based on the general methodology of UB as the difference between total composite utilities calculated before and after the project introduction. The current FTA approach limits the corresponding scope of choices (over which the composite utility is calculated) to mode and route choices. Thus, the total trip table is assumed fixed and the mode and route choice attributes that are necessary for calculation of the composite mode choice utility are reported. The FTA approach and developed software SUMMIT have been primarily designed for 4-step models that are characterized by an easy disintegration of the trip-distribution and mode-choice stages as well as aggregate zone-to-zone structure of the model output. The new generation of activity-based tour-based micro-simulation models of which the Mid-Ohio Regional Planning Commission (MORPC) model is one of the representatives, requires a certain reconsideration of the UB calculations in view of the more complicated structure where trip distribution and mode choice stages are closely intertwined as well as because of the fully-disaggregate (individual record) structure of the output.

In theoretical terms, the behaviorally realistic and detailed output of the new models offers numerous additional possibilities for quantifying UB of transit projects compared to the composite mode choice utility. However, taking advantage of the activity-based approach for the UB calculation is a long-term issue where numerous methodological and technical details should be worked out yet. Also, extending the UB methodology for activity-based models (though highly desirable) may create a certain bias in the comparison between regions since some of MPOs have already developed activity-based models while the majority of MPOs are still using conventional 4-step models. Under these circumstances and primarily for practical purposes, we propose a constructive way to adjust the activity-based model output to the requirements of the conventional UB calculation procedure.

The general structure of the MORPC model system and the most important and relevant components are shown in the **Figure 1** below. A set of day-level models that corresponds to coordinated daily activity patterns for all household members, is presented as a single upper-level stage with no details since the current paper is devoted to the mode choice issues.

The subset of tour-level models includes the following components:

- Primary tour destination model that defines which of 1,805 zones and which of 3 sub-zones (with no access to transit, long walk to transit of 0.5-3.0 mile, or short walk to transit less than 0.5 miles) are chosen for each tour.
- Time-of-day model that defines departure-from-home and arrival-back-home combination of hours from 5:00 AM (or earlier) to 23:00 PM (or later). Departure-from-home hour is associated with the outbound half-tour timing and arrival-back-home is associated with the inbound half-tour timing.
- Entire-tour mode / best transit sub-mode model that defines which entire-tour mode out of 6 principal modes (1-SOV, 2-HOV, 3-Walk to Transit, 4-Drive to Transit, 5-Non-Motorized, 6-School Bus) is chosen for each tour, and for Walk-to-Transit and Drive-to-Transit tours – which transit sub-mode out of 5 sub-modes (1-local bus, 2-express bus, 3-BRT, 4-LRT, 5-commuter rail) is chosen for each half-tour.
- Stop-frequency model that defines if there is an intermediate stop at each of half-tours. Since only one potential stop on each half-tour is considered, the model at the tour level has only 4 explicitly modeled alternatives (1-no stops, 2-outbound stop, 3-inbound stop, 4-stops on both half-tours).

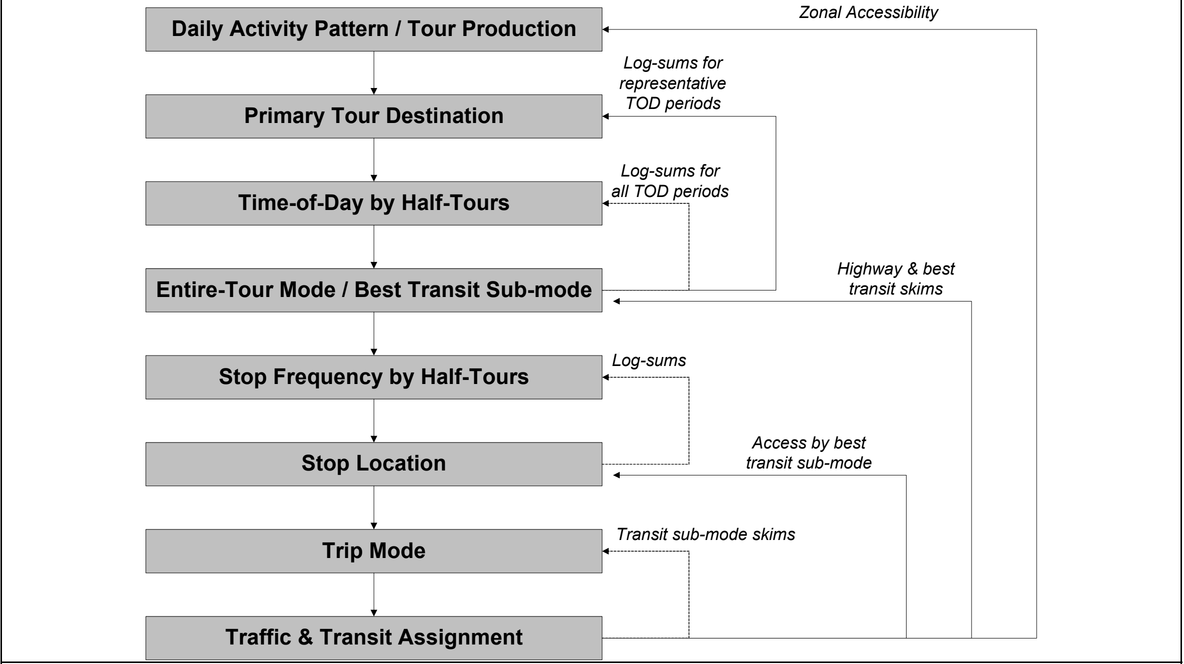

Figure 1: General structure of the MORPC model system

Two subsequent models relate to the following trip-level choices that are conditional upon the previously made tour-level decisions:

- Stop-location model that defines a location for each stop at the same level of spatial resolution as primary destination (1,805 zones and 3 transit-access sub-zones for each zone). Stop location availability is strongly conditional on availability of the chosen tour mode and transit sub-mode to access the location.
- Trip mode model that defines mode and transit sub-mode for each trip on the tour. If there is no stop on a half-tour, the whole half-tour is considered as one trip and the chosen mode and transit sub-mode are preserved. If there is a stop, the half-tour is broken into two successive trips (to and from the stop).

After processing through all tour-level and trip-level stages, trip tables are constructed for all modes and transit sub-modes. These tables are assigned to the corresponding highway and transit sub-networks. Loaded networks are skimmed to produce level-of-service attributes necessary for the models. The model system is designed to process through several global iterations including all (or a chosen sub-set) of models and network assignments until an equilibrium is reached.

Additionally, several important "upward" linkages of the choice models through log-sums from the lower-level choices used in upper-level choices are incorporated:

- Entire-tour bi-directional mode choice log-sums for the representative time-of-day periods (for example, AM/PM combination for work tours and AM/MD combination for school tours) are used as variables in the primary tour destination choice models; the reason why only representative mode choice log-sums are used in the destination choice is that this choice dimension has 1805×3=5,415 alternatives and is extremely computationally intensive.

- Entire-tour bi-directional mode choice log-sums for all time-of-day periods are used as variables in time-of-day choice; since the time-of-day choice model is applied conditional upon the chosen destination it is significantly less intensive computationally compared to destination choice and it is possible to explicitly consider mode choice log-sums for all possible time-of-day combinations.
- Stop-location log-sums (behaviorally interpreted as density of stop attractions on the way to and from the primary destination) are used as variables in the stop-frequency model; these log-sums are calculated for each half-tour and take into account stop location access by the chosen tour mode and transit sub-mode.

The tour-based structure imposes some problems in the way how the model outputs can be compared for the "base" and "build" scenarios. The core complication is that both trip distribution and mode choice stages are closely intertwined and cannot be fully separated. Indeed, the former single trip distribution stage is divided into primary tour destination choice and stop-frequency/location choice. The former mode choice stage is divided into entire-tour mode choice and trip mode choice. These choices are sequenced in a way where pure trip distribution and mode choice stages cannot be combined back in a simple trip format. Consequently, the basic requirement of "fixed trip table" cannot be met without some enforcement in the model chain. However, there are three possible constructive ways to meet the FTA requirements at least on a partial basis and provide meaningful inputs for UB calculation that can be processed by SUMMIT. These three options are outlined in the **Table 1** below.

Table 1: Three options for comparison of transit alternatives

Model stage / feature	**Option 1**	**Option 2**	**Option 3**
Tour generation	Fixed	Fixed	Fixed
Tour primary destination	Fixed	Fixed	Fixed
Tour time-of-day	Fixed	Fixed	Fixed
Tour mode	Variable	Variable	Variable
Stop frequency	Variable	Fixed	Fixed
Stop location	Variable	Variable	Fixed
Trip mode choice	Variable	Variable	Variable
Tour OD tables by TOD periods	Fixed	Fixed	Fixed
Trip OD tables by TOD periods	Variable	Variable but totals are fixed	Fixed
Report to SUMMIT	Simplified tour-level mode choice log-sum w/o intermediate stops	Simplified tour-level mode choice log-sum w/o intermediate stops	Full tour-level mode choice log-sum with LOS variables reflecting frequency and location of intermediate stops
Included components	Differences in mode utilities w/o stops	Differences in mode utilities w/o stops	Full differences in entire-tour mode utilities including LOS variables associated with making stops
Ignored components	Additional LOS components associated with making stops; A certain incomparability of LOS variables for alternatives with different number of trips on the tour and different stop locations	Additional LOS components associated with making stops; A certain (but less significant) incomparability of LOS variables for alternatives with the same number of trips on the tour but different stop locations	

Currently, the first (simplest) option has been adopted for the MORPC model and implemented programmatically. According to this approach a full micro-simulation model (with several global iterations including all steps) is run for the “base” scenario. Then, all tours are fixed with their primary destinations and the “build” scenario is run for several iterations including only mode, stop frequency, and stop location choices as well as assignments.

The model output that is directly used for the UB calculation relates to the tour-level mode choice statistics only. Technically, it is very similar to the conventional model output where trip units are replaced with tour units. The impact of other choices (stop frequency, stop location, trip mode choice) is taken into account implicitly through the overall iterative equilibration of travel times and cost and upward log-sums included into the tour-level mode choice utilities.

The individual-record format can be converted into the quasi-aggregate format that corresponds exactly to the conventional SUMMIT input. The conversion is based on the following rules:

- All tour records with identical production zone, attraction zone, socioeconomic market segment, travel purpose, and time-of-day are collapsed into a single (aggregate) record with the corresponding values for these fields.
- The other fields for the aggregate record are processed in the following way:
    - Person trips are totaled across the aggregated records.
    - Fractions of trips that have a Walk-to-Transit path and Drive-to-Transit-only, as well as Walk-to-Transit and Drive-to-Transit-only shares are averaged across the aggregated records (which makes their values fractional).

The only non-trivial transformation that requires explanation is the aggregation of non-transit exponentiated utility. Introduce the following notation:

$i = 1,2,...,I$ = choice alternatives,
$n = 1,2,...,N$ = individual records to be aggregated within the group,
V_{in} = known individual utilities,
$P_n(i)$ = known individual probabilities,
W_n = person “trips” (1-for individual tours, party size for joint tours),
V_i = unknown aggregate utilities,
W = total person “trips” for the group.

The idea of utility aggregation is to find a utility expression that would: 1) exactly replicate aggregate mode shares and 2) exactly replicate total composite utility over all individual records and consequently replicate a user benefit calculation. The aggregate mode shares for the group of records can be readily calculated as follows:

$$P(i) = \frac{\sum_{n=1}^{N} W_n \times P_n(i)}{W}. \qquad \textbf{Equation 1}$$

The first condition (replication of aggregate shares) leads to the following expression:

$$V_i = \ln[P(i)] + C,$$ **Equation 2**

where C denotes a utility scale constant that has to be determined.

The second condition (replication of the composite utility) leads to the following expression (for simplicity we assume that the choice model is a simple MNL and the composite utility is calculated as a simple one-level log-sum):

$$W \times \ln\left[\sum_{i=1}^{I} \exp(V_i)\right] = \sum_{n=1}^{N} W_n \times \ln\left[\sum_{i=1}^{I} \exp(V_{in})\right].$$ **Equation 3**

By an equivalent transformation of the equation 3 we obtain:

$$\sum_{i=1}^{I} \exp(V_i) = \exp\left\{\sum_{n=1}^{N} \frac{W_n}{W} \times \ln\left[\sum_{i=1}^{I} \exp(V_{in})\right]\right\} = \prod_{n=1}^{N}\left[\sum_{i=1}^{I} \exp(V_{in})\right]^{\frac{W_n}{W}}.$$ **Equation 4**

By substituting the expression for aggregate utilities from the equation 2 to equation 4 we obtain the necessary formula for the utility scale C:

$$\sum_{i=1}^{I} \exp(V_i) = \exp(C) \times \sum_{i=1}^{I} P(i) = \exp(C) = \prod_{n=1}^{N}\left[\sum_{i=1}^{I} \exp(V_{in})\right]^{\frac{W_n}{W}}.$$ **Equation 5**

Now combining equations 2 and 5 we obtain the expression for aggregate exponentiated utilities that would exactly reproduce the target market shares and user benefits:

$$\exp(V_i) = P(i) \times \exp(C) = P(i) \times \prod_{n=1}^{N}\left[\sum_{i=1}^{I} \exp(V_{in})\right]^{\frac{W_n}{W}}.$$ **Equation 6**

The equation 6 has a simple intuitive interpretation. The aggregate exponentited utility of each mode is proportional to a product of two factors. The first one is equal to the aggregate mode share and reflects how each mode is improved versus the other (competing) modes. The second one is equal to the weighted geometric average of the individual (exponentiated) log-sums; this component is sensitive to the overall improvement of all modes.

This aggregation calculation should be implemented separately for the "base" scenario and "build" scenario and for each group of aggregated records. The same way, how this aggregation can be applied for mode utilities, it can be applied for the composite non-transit utility as well as it can be generalized for any nested structure by using a full mode choice log-sum for each individual record LS_n. The aggregate exponentiated non-transit utility can be calculated as follows:

$$\exp(V_{NT}) = [P(SOV) + P(HOV) + P(NM) + P(SB)] \times \prod_{n=1}^{N} [\exp(LS_n)]^{\frac{W_n}{W}}.$$ **Equation 7**

The described methodology of UB calculation was applied for the analysis of the recent LRT project in Columbus, Ohio and was approved by FTA. The results are provided in the companion paper.