Combinatorial tour mode choice

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Objectives and motivation
In most Activity-Based Models (ABMs) in practice mode choice decisions are modeled in two steps. First the entire-tour mode combination is predicted based on the location of the primary destination of the tour (at this step the modeled tour is largely treated as a simple round trip). Secondly, a detailed trip mode is predicted conditionally upon the tour mode and given the specific origin and destination for each trip.

The mode choice model applied for the ABMs recently developed for the Maricopa Association of Governments (MAG) and Ohio state DOT (ODOT) has a different structure where the tour-level and trip-level choices are integrated in a network combinatorial representation. The model considers all feasible trip mode combinations on the tour. This model formulation imposes many constraints compared to the two-step structure and in particular, with respect to the conditional linkages determined by the sequence of trip mode choices within the tour. This structure explicitly tracks the car status at origins and destinations of each trip and constrains multi-model combinations such as Park-and-Ride (PNR) to a logical location of the parking lot. This approach suits some of the recent ABMs developed in practice where tour formation sub-model precedes tour mode choice in the model chain and eventually both models are equilibrated.

Statement of innovations
This research was intended to improve the structure of tour-based mode choice models and take advantage of several parallel developments in route choice models that are tackling similar problems:

- Ensure a full consistency between the tour-level and trip-level mode choice models and with a consideration of actual locations of all stops on the tour,
- Take into account multiple combinatorial constraints on available trip modes with an explicit tracking of car status at each trip end,
- Integrate multi-modal combinations, and specifically, PNR lot location choices into the trip mode choice structure in a consistent way for the entire tour,
- Avoid an explicit enumeration of all possible trip mode combinations both in the model application by applying an efficient network shortest path algorithm and in model estimation by applying a parsimonious choice set structure for each trip,
- Account for differential similarities between trip mode combinations by simulating correlated error terms for tour modes from trip-mode error terms.

Tour mode combinations
In the current research, 14 trip modes \( (m) \) were defined as shown in Table 1 and for each tour the mode label (1-14) was assigned using predetermined priority rules for both processing the Household Travel Survey (HTS) data and processing the model output in all steps of model estimation and validation. Analysis of the observed trip mode combinations in the HTS for both MAG and three Ohio regions have
shown similar patterns. In most cases (more than 70%) and especially for simple 1-destination tours (with 2 trips), trip mode was the same for all trips on the tour. However, there was a substantial number of cases, and especially for complex multi-destination tours, where the tour mode combination included more than one mode for the following reasons:

- Asymmetric tours with outbound and inbound modes not being equal, for example, when the traveler was driven as HOV passenger in one direction and used transit in the opposite direction,

- Variety of transit modes used for different trips on the same tour; in the current research this variety was somewhat suppressed by defining only 2 principal transit modes (conventional and premium); it could be presented with more detailed classification of transit modes (local bus, express bus, LRT, BRT, subway, rail, etc),

- Frequent car occupancy change (SOV, HOV/2, HOV/3, etc) from trip to trip on auto tours; a systematic strong pattern was observed with occupancy most frequently growing towards the home end of each half-tour. In the outbound direction, car occupancy is most frequently maximal when the tour starts from home and it gradually decreases towards the primary destination due to the possible drop-offs of passengers. In the inbound direction, car occupancy most frequently minimal at the primary destination and it gradually increases towards the arrival back home due to the possible pick-ups of passengers.

- Bi-modal tours such as Park-and-Ride (PNR) and Kiss-and-Ride (KNR) with stops. One frequent case includes starting from home with a child, dropping off a child at school, then parking a car at transit station, going to work by transit, going back to parking station by transit, taking the car from the parking lot, stopping for shopping, and then going back home. This PNR tour would include the following sequence of trip modes “HOV-driver, PNR, reversed PNR, SOV”.

- Non-motorized trips on motorized tours. Many cases of walk trips were observed on motorized tours including both auto and transit tours. Walk trip sub-chains on motorized tours are frequent when the primary destination is in a dense urban area such as CBD.

### Car status and feasible combinations of trip modes

One of the key factors in modeling a consistent tour mode combination is to properly track car use across the sequence of trips. In the proposed model structure, car status ensures consistency among trip modes in a feasible combination. At any trip origin or destination the car status ($s$) is classified into 4 possible states:

1. “Car from home” which means that until this point the car was used on all preceding trips and has never been parked outside home, hence car is available for the subsequent trip.
2. “Car parked” which means that car was used originally (at least for the first trip from home) but it was subsequently parked outside home on one of the preceding trips, hence the car is not available for the subsequent trip.
3. “Car from parking” which means that car was parked earlier on this tour but then it was taken upon return trip to the parking lot and is available for the subsequent trip.

4. “No car on tour” which means that a car was not used for the very first trip on the tour and hence it is not available for any subsequent trip.

Tracking car status at trip origin and destination provides many logical constraints on the trip mode choice as shown in Table 1 below. Taking into account that car status at a trip destination defines car status at the origin of the subsequent trip, this creates a formal framework for description of all possible feasible trip mode combinations for a tour.

Table 1: Feasible combinations of trip origin car status, trip mode, and trip destination car status

<table>
<thead>
<tr>
<th>Car status at trip origin</th>
<th>Trip mode</th>
<th>Car status at trip destination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1=Car from home</td>
<td>3=Car from parking</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>1=SOV/driver</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>2=HOV2/driver</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>3=HOV3+/driver</td>
</tr>
<tr>
<td>X</td>
<td>4=HOV/passenger</td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>5=Conventional transit/walk</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>6=Conventional transit/KNR</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>7=Conventional transit/PNR</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>8=Premium transit/walk</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>9=Premium transit/KNR</td>
</tr>
<tr>
<td>X</td>
<td>10=Premium transit/PNR</td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>11=Walk</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>12=Bike</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>13=Taxi</td>
</tr>
<tr>
<td>X</td>
<td>14=School bus</td>
<td>X</td>
</tr>
</tbody>
</table>

Model formulation for feasible tour mode combination

A tour mode combination is considered feasible if it obeys the system of logical constraints imposed across multiple dimensions. Basic feasibility rules are applied in a framework of sequential joint choice of mode and destination car status for each trip conditional upon the car status at the trip origin. The application of feasibility rules for the entire sequence of trips in a tour ensures that not trip sequence can include impossible combinations of trip modes.

There are also additional rules that further truncate the possible combination of trip modes but they are imposed using the same technique. In particular, and based on observed tour mode combinations, it was useful to specify these feasibility matrices separately for outbound and inbound half-tours as well as
constrain the number of car status switches for 2 to 3 and from 3 to 2 as well as request that the car taken from home should always arrive back home. Also, it should be noted that the described logical constraints are combined in model estimation and application with the usual trip-level mode constraints (for example, transit availability) and individual constraints (car availability, driver license, joint travel, etc) that further truncate the set of possible mode combinations.

It is useful to present the feasibility constraints as a decision making tree where the variety of available modes for each subsequent trip is branched out of the chosen modes and car statuses for the previous trips. An example of a full tree with 3 modes (1=SOV, 2=conventional transit/walk, 3=conventional transit/PNR, where the number of modes was reduced for illustration purposes) and 4 car statuses is shown in Figure 1 below for a 3-trip home-based tour. In this example, we assume that the first two trips are in the outbound direction where PNR with switching to car status 2 is available while the third trip is in the inbound direction where only a reversed PNR with switching to car status 3 is available. Note that only two car statuses (1 and 4) are available from the beginning of the tour (origin of first trip) and only three car statuses (1, 3, and 4) are available for the end of the tour (destination of the last trip).

Figure 1: Feasible combinations of trip modes and car statuses on a 3-trip tour
This simple example illustrates the importance of a proper constraining of trip mode and car status combinations. While a simplified Cartesian consideration of all possible trip mode/car status combinations results in $3^3 = 27$ combinations, the actual number of feasible combinations with a logical car tracking is only 6.

**Specifics of trip mode utility function for combinatorial model**

Two important specifics differentiate this trip mode utility structure from that of a standard mode choice model. The first relates to entire-tour effects and transaction costs associated with mode switches where utility $V_t(m)$ is dependent on the choices implied by previous trips in the feasible mode and car status combination. The most statistically significant mode transaction effects included:

- Transit mode switching penalties that reflect fare discounts and/or transit pass consideration and make transit mode fare for the given trip a function of the previously chosen transit modes.
- Car occupancy switching penalties that reflect systematic car occupancy changes by direction where passenger drop-offs happen mostly in the direction from home, while passenger pick-ups happen mostly in the direction towards home.
- PNR symmetry, i.e. taking a car from the same parking lot it was originally parked; this utility component is not a statistically estimated penalty but a constraint on how LOS variables are calculated for the reversed PNR trip. Distance, travel time, and cost for inbound reversed PNR are conditional upon the chosen parking location in the outbound PNR trip. Since choice of both the outbound and reversed PNR trips are part of the feasible entire-tour alternative, the choice of PNR lot is also somewhat optimized [Error! Reference source not found.].

The second aspect is that the utility function for each trip and mode should be structured in such a way that it would always be negative: $V_t(m) < 0$. This is essential for an efficient application algorithm that borrows from the network shortest path techniques. For this reason, the mode utility structure and estimation were specified to have only negative constants and negative coefficients on positive variables (such as travel time and cost).

**Model estimation as recursive logit model**

It is possible to estimate this model by an explicit enumeration of all possible mode combinations for each tour. This however, would require forming a choice model with a very large set of alternatives (at least for some tours with 3+ trips) and this set would be further exploding exponentially if the mode details are added despite the fact that the mode combination tree is substantially truncated by the feasibility rules and car status tracking. To overcome this problem and take advantage of the network analogy between the mode choice and route choice, we applied an innovative recursive logit model (suggested by Fosgerau) that was suggested for estimation of route choice models in a large network where a complete enumeration of all paths is infeasible.
Model application as stochastic network shortest path problem
Network representation of the tour mode combinatorial choice model allows for application of an efficient network Shortest Path (SP) algorithm that does not require a full enumeration of all mode combinations and additionally does not require a computationally expensive evaluation of trip mode utility functions for all nodes of the path tree (Figure 1).

To illustrate, a frequent case with the mode combination presented in (Figure 1) in a practical application is that the combination with all trips made by 1=SOV and car status equal to “1=Car from home” will be optimal. In most cases the Dijkstra algorithm would evaluate four alternatives (mode and car status at the destination) for the first trip and identify the “1=SOV/1=Car from home” as the most attractive one. Then this alternative will be re-chosen for the second trip and similarly for the third trip without branching out of the other nodes since their utility will likely not be competitive after evaluation of the first trip. Thus, in terms of the number of utility calculations, the most time-taking component of the entire model, only 6 utilities will be evaluated out of a potential 16. The computational savings for a full set of modes for tours with more than 3 trips is substantial.

Similar tour mode combinations (overlapping routes) taking into account by having the random error term generated in advance for each mode and trip combination. Overlapping routes will have more common random terms and will be more correlated. Accounting for route overlapping in a microsimulation framework is easier to implement through generating an additive-by-link error term rather than through a complex entire-route random term. A similar approach was used to resolve the route overlapping problem in network route choice.

Major results overview
The developed model was applied and validated as part of the new ABMs developed for the metropolitan regions of Phoenix, AZ and Columbus, OH with generally very good results. The short format of the research brief does not allow for presentation of the results. The full paper and presentation includes the following detailed comparisons between the model results and expanded HTS:

- Replication of 14 tour mode shares by 7 aggregate tour types and travel purposes (1=work, 2=university, 3=school, 4=escorting, 5=individual non-mandatory, 6=joint non-mandatory, 7=at work),
- Replication of 14 trip mode shares by 7 aggregate tour types and travel purposes,
- Replication of 14 trip mode shares by 14 tour modes,
- Replication of tour-length distribution by tour mode,
- Replication of trip-length distribution by trip mode.

The full paper and presentation also contain a sensitivity test with applying a regional network of toll roads and managed lanes that targeted moving people from SOV to HOV and from auto to transit in general. The results proved to be logical and showed some resistance to switch for certain travel markets such as tours that include an escorting stop and multi-destination tours in general.