Application Experience of New Approach to Tour-formation in Activity-Based Model Framework

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Introduction and Motivation

In the activity-based approach to travel demand modeling, travel is derived from activities, i.e. the central unit of modeling is an activity in which an individual intends to participate during the day. However, most Activity-Based Models (ABMs), both in practice and research, do not entirely incorporate this central idea. The most frequently used ABMs in practice generate travel tours up-front and subsequently add details on intermediate stops in each tour. Other ABMs generate activities in which a traveler intends to participate, but they still apply a series of tour frequency and stop-insertion models (conditional upon the activity participation) to model daily travel. This framework is largely borrowed from tour-based travel demand models, where the basic unit for travel analysis is the tour rather than activity. To a certain extent, this approach contradicts the basic idea of ABMs – that the major unit of analysis is activity from which travel (tours and trips) should be derived. In reality, most people do not make up-front decisions about how many tours to undertake and how many stops to make within each tour. These tours and corresponding trips emerge from their activity participation, potential activity location, and activity sequence choices, coupled with time and space constraints imposed by activities with relatively lower spatial and temporal flexibility. This paper explores and validates a novel approach to model daily travel in an ABM, by generating activities first and forming tours as a second step.

The modeling approach recently incorporated in Coordinated Travel - Regional Activity Modeling Platform (CT-RAMP) can be classified as a new tour-formation approach in which tours are formed, instead of generated, based on the spatial and temporal constraints imposed by less flexible and previously scheduled activities. This approach has been adopted for the Ohio 3C (Columbus, Cincinnati/Dayton, and Cleveland), Phoenix, and Jerusalem ABMs. This paper shows the application results of the new tour-formation approach based on the implementation results for Ohio.

Methodology

For each person and household, the activity generation and tour-formation decisions are organized into the following four major steps:

1. Generation of mandatory activities and formation of mandatory tour skeletons. This step includes decisions that relate to the least flexible activities. In reality, many of these activities are pre-planned before the given day and a person builds his or her daily activity pattern and schedule around them (see Paul et.al. 2015).
2. Generation of intra-household shared non-mandatory activities and formation of fully joint tours.
3. Allocation of individual non-mandatory activities to person-day segments resulting from the scheduling of prioritized activities considered in the first two steps (see Vyas et.al. 2015).
4. Within-segment activity sequencing and tour-formation. The final tour-formation step is modeled for each day segment separately. This step is a single model which jointly models the sequencing, location and tour breaks for the chain of non-mandatory activities in person-day segments (see Paul et.al. 2015).
The prioritized activities, characterized by inflexible schedule and fixed location, are scheduled first for each individual. These prioritized activities divide the entire day into day segments and thus creates pegs in the daily schedule around which the subsequent tour-formation process is organized. The day segments can be one of following three types:

1. **Type 1**: Segment between the prioritized-activity tours. These allocations generate individual home-based non-mandatory tours in addition to already generated prioritized tours.

2. **Type 2**: Outbound and inbound legs of prioritized tours. These allocations do not result in any new tours but increase the number of stops in the prioritized tours. For multiple commute tours, Type 2 refers to the outbound leg of the first commute tour and inbound leg of the last commute tour.

3. **Type 3**: This category corresponds to non-work activities undertaken at a workplace that result in at-work sub-tours that start and end at the workplace. For example, a worker going out for lunch during office hours is categorized as Type 3 allocation of the eating-out activity.

The non-prioritized non-mandatory activities are then allocated into these day segments. As an example, consider a worker with 1 work activity as the prioritized activity in the day. Even for such a simple pattern with a single “peg” (i.e. single work prioritized activity) there are 5 possible ways to allocate an additional non-mandatory activity (say, shopping):

1. Before work with return home prior to going to work (Type 1 segment)
2. On the way to work as a stop (Type 2 segment)
3. At work as a sub-tour (Type 3 segment)
4. On the way home from work as a stop (Type 2 segment)
5. After return home from work as an individual tour (Type 1 segment)

After the allocation of non-prioritized activities in day segments, tours are formed based on the spatial and temporal constraints imposed by prioritized activities. The tour-formation step consists of three decisions which are modeled simultaneously:

1. Sequencing of activities (along with prioritized activities for type 2 & 3 segments).
2. Location of activities.
3. Tour structure – single tour or multiple tours with additional stops at home (type 1 segment) or at work (type 3) segment.

The choice set for this step is the union of location alternatives for all activities with an option for tour “break” (i.e. visiting home as yet an additional stop in the chain). The implemented analysis at the individual level and estimated choice models for tour-formation provided many useful insights into the associated behavioral preferences that would be difficult to address with a standard tour-based model structure. Consider the example of two non-mandatory activities – shopping (S) and maintenance (M) allocated into the same Type 1 segment. According to the observations in real surveys and given the structure of the tour-formation model described above there can be four possible tour-formation outcomes depicted using notation {H} for home:

1. H-S-M-H (single tour)
2. H-M-S-H (single tour)
In terms of decision-making, there are three intertwined aspects reflected in the model:

1. **Sequencing of activities** (Shopping first, maintenance second or vice versa?). The estimated model showed that there is strong statistical evidence for certain sequencing priorities captured at the pair-wise activity level that are also related to the usual opening and closing hours of the corresponding establishments.

2. **Location of activities.** The estimated location component of the tour-formation model is similar to a conventional destination choice with the zonal size variable and impedance function. However, the impedance function was restructured to reflect on the entire-tour framework with moving anchor points for each subsequent activity.

3. **Presence of an additional stop at home that “breaks” the activity chain into two tours.** This model component, essentially, plays the role of tour-frequency model. However, the principal difference from the conventional tour-frequency model is that the decision of stop at home is modeled simultaneously with the activity locations. In reality, activity location is one of the most important factors shaping the tour structure. In this example, if both activities are located far from home but close to each other, the tour break is less probable. The closer the activities to home and farther away from each other the higher is the probability of breaking this chain and having two tours. In this regard, the adopted tour-formation structure captures the underlying “travel optimization” aspect that proved to be very significant statistically.

It should be noted that the tour-formation step does not include any explicit tour frequency or stop frequency model. The tours and stops emerge from the modeled choices considering the given set of activities in each segment, individual preferences with respect to the sequencing of activities, activity supply side (attraction or size variable by zone), as well as spatial and temporal constraints or the entire window for the modeled segment. The tour-formation model also incorporates both primary destination and stop-location choices in one consistent framework.

**Major Implementation Results**

The focus of analysis of the implementation results of the tour-formation model was on the emerging properties of the subsequent tours that are not directly controlled. The primary research interest was on how the emerging tour properties vary by tour complexity. The modeled tour frequency, stop frequency, and the resulting total tour length were compared to the corresponding statistics from the Household Travel Surveys (HTS) to evaluate the performance of the tour-formation model. Instead of a straightforward comparison of the average tour frequency, stop frequency and tour length with the data from the HTS, a deeper structural analysis was implemented with the emerging tour characteristics by different day segments. The idea was to analyze the tour characteristic in different temporal and spatial pressure conditions. The model was estimated using the pooled dataset from HTSs for Columbus, Cincinnati, Cleveland, and Dayton. The developed tour-formation model was then applied as a test to the smaller city of Lima, Ohio as part of a complete ABM that provided outputs of all prior sub-models.
starting from the population synthesizer. The resulting tour frequency by day segment is shown in Figure 1 and stop frequency and tour length distribution by day segment are shown in Table 1. In all cases the model output for Lima is compared to the HTS for Columbus, which was the closest proxy to Lima in terms of urban structure, although Columbus is much a bigger city than Lima. The data in both the Table and the Figure are given for situations in which at least one activity is generated.

When comparing the tour-formation results of the model to HTS statistics it should be taken into account that all possible discrepancies in the prior sub-models in the model chain (for example, activity generation at the daily level) can affect the tour-formation model as well. Thus analysis shown below should be thought of as an application results evaluation of the entire ABM inclusive of the tour-formation model rather than a test for a pure tour-formation model itself.

The “all day” segment was singled out from other Type 1 segments. In this case, the person does not have any mandatory activities, joint tours, or other “pegs,” a frequently observed case for adult non-workers. Although technically an all-day segment is processed as any Type 1 segment with formation of individual non-mandatory tours, the time-space constraints for a non-worker with the whole day available are quite different from time-space constraints of a worker with a Type 1 segment, who is limited to a time window before or after work. The model did not have any particular constants for “all day” segments and it was important to verify that the parametric specifications of the choice utility functions reflecting the available time windows and other variables would capture such a special case adequately. The differences in individual non-mandatory tour frequency between people with no other prioritized activities and people with other prioritized activities shows the importance of time-space constraints in the travel pattern.
Figure 1: Tour frequency distribution by day segments
Table 1: Stop frequency and tour length distribution by day segments

### Type 1 - All Day

<table>
<thead>
<tr>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>152,762</td>
<td>58%</td>
<td>6.87</td>
<td>1</td>
<td>4,423</td>
<td>44%</td>
<td>7.38</td>
</tr>
<tr>
<td>2</td>
<td>51,719</td>
<td>20%</td>
<td>11.14</td>
<td>2</td>
<td>2,323</td>
<td>23%</td>
<td>11.13</td>
</tr>
<tr>
<td>3</td>
<td>27,586</td>
<td>10%</td>
<td>13.37</td>
<td>3</td>
<td>1,628</td>
<td>16%</td>
<td>14.39</td>
</tr>
<tr>
<td>4</td>
<td>16,347</td>
<td>6%</td>
<td>19.69</td>
<td>&gt;4</td>
<td>982</td>
<td>10%</td>
<td>17.21</td>
</tr>
<tr>
<td>&gt;4</td>
<td>16,356</td>
<td>6%</td>
<td>28.61</td>
<td>&gt;4</td>
<td>791</td>
<td>8%</td>
<td>21.70</td>
</tr>
</tbody>
</table>

### Other Type 1

<table>
<thead>
<tr>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>176,479</td>
<td>66%</td>
<td>3.76</td>
<td>1</td>
<td>2,169</td>
<td>42%</td>
<td>5.00</td>
</tr>
<tr>
<td>2</td>
<td>54,574</td>
<td>20%</td>
<td>7.02</td>
<td>2</td>
<td>1,483</td>
<td>29%</td>
<td>8.50</td>
</tr>
<tr>
<td>3</td>
<td>21,030</td>
<td>8%</td>
<td>10.70</td>
<td>3</td>
<td>963</td>
<td>19%</td>
<td>10.77</td>
</tr>
<tr>
<td>4</td>
<td>10,414</td>
<td>4%</td>
<td>14.62</td>
<td>&gt;4</td>
<td>376</td>
<td>7%</td>
<td>13.37</td>
</tr>
<tr>
<td>&gt;4</td>
<td>6,544</td>
<td>2%</td>
<td>24.27</td>
<td>&gt;4</td>
<td>179</td>
<td>3%</td>
<td>16.23</td>
</tr>
</tbody>
</table>

### Type 2

<table>
<thead>
<tr>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>167,038</td>
<td>70%</td>
<td>4.47</td>
<td>1</td>
<td>2,548</td>
<td>24%</td>
<td>6.09</td>
</tr>
<tr>
<td>2</td>
<td>45,110</td>
<td>19%</td>
<td>8.99</td>
<td>2</td>
<td>2,972</td>
<td>28%</td>
<td>10.39</td>
</tr>
<tr>
<td>3</td>
<td>16,607</td>
<td>7%</td>
<td>15.27</td>
<td>3</td>
<td>2,996</td>
<td>28%</td>
<td>12.85</td>
</tr>
<tr>
<td>4</td>
<td>7,180</td>
<td>3%</td>
<td>18.46</td>
<td>&gt;4</td>
<td>1,471</td>
<td>14%</td>
<td>16.17</td>
</tr>
<tr>
<td>&gt;4</td>
<td>3,624</td>
<td>2%</td>
<td>20.02</td>
<td>&gt;4</td>
<td>773</td>
<td>7%</td>
<td>19.02</td>
</tr>
</tbody>
</table>

### Type 3 (At-work subtours)

<table>
<thead>
<tr>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
<th>Number of activities on tour</th>
<th>Number of tours</th>
<th>Stop frequency distribution</th>
<th>Average Tour Length (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>63,921</td>
<td>73%</td>
<td>3.22</td>
<td>1</td>
<td>848</td>
<td>62%</td>
<td>6.04</td>
</tr>
<tr>
<td>2</td>
<td>15,618</td>
<td>18%</td>
<td>5.74</td>
<td>2</td>
<td>278</td>
<td>20%</td>
<td>9.62</td>
</tr>
<tr>
<td>3</td>
<td>5,827</td>
<td>7%</td>
<td>9.67</td>
<td>3</td>
<td>166</td>
<td>12%</td>
<td>12.50</td>
</tr>
<tr>
<td>4</td>
<td>1,045</td>
<td>1%</td>
<td>14.82</td>
<td>&gt;4</td>
<td>59</td>
<td>4%</td>
<td>15.37</td>
</tr>
<tr>
<td>&gt;4</td>
<td>889</td>
<td>1%</td>
<td>46.95</td>
<td>&gt;4</td>
<td>18</td>
<td>1%</td>
<td>14.46</td>
</tr>
</tbody>
</table>
A complete replication of tour characteristics was not expected as these characteristics were not controlled during estimation and implementation of the model. Moreover, the demographic differences between Lima and Columbus contribute to the differences in tour characteristics. Nonetheless, on comparing the emerged tour characteristics with the HTS, it can be seen that emerged characteristics of tours are very much in line with the observed tours in the HTS. The tour length was expected to increase with an increase in the number of stops, but not linearly as can be concluded from Table 1. There is a diminishing rate of growth in the tour length with the addition of a stop on the tour. The time pressure has a significant effect on the tour length distribution as tours tend to be longer if individuals have more time available for activities and travel in the corresponding day segment window.

**Conclusions**

This paper presented the application results of a new framework to model daily travel in ABMs by generating activities first and then forming tours as a second step. The central idea of this modeling approach is based on a plausible assumption that certain inflexible or prioritized activities are scheduled first and then other activities are built (in terms of schedule and locations) around these prioritized activities. This modeling approach results in a chain of four models that deals with 1) generation and scheduling of prioritized activities and associated tour skeletons, 2) formation of day segments, 3) allocation of other activities to these day segments, and 4) tour-formation.

A deep structural analysis was implemented to evaluate the application results of the tour-formation model. The emphasis was on analyzing the impact of temporal and spatial constraints on daily travel, with a reasonable replication of observed travel characteristics. The implemented results confirmed that temporal and spatial constraints represent a very important aspect of daily travel. The tour-formation model is not just a more behaviorally appealing decision-making chain embedded in the ABM, but can have important implications for policy testing and project evaluation.

The entire ABM and the tour-formation model in particular are currently under an intensive validation, calibration, and sensitivity testing process. The full paper and presentation contain many more results that will be updated by the time of the conference. One additional aspect that cannot be addressed in the short research brief but will be addressed in the full paper and presentation is the model sensitivity to changing travel and/or urban conditions.

**References**