1. Introduction

The new travel demand model developed for the Mid-Ohio Regional Planning Commission (MORPC) located in Columbus, OH represents an advanced modeling structure that belongs to the new generation of travel demand models along with the San-Francisco County model (SFC), Portland METRO model, and the New York Metropolitan Transportation Council (NYMTC) model. The new generation of regional travel demand models is characterized by the following three base features:

1. **Activity-based** platform, that implies that modeled travel be derived within a general framework of the daily activities undertaken by households and persons including in-home activities, intra-household interactions, time allocation to activities, and many other aspects pertinent to activity analyses, but typically missing in the conventional travel demand models.

2. **Tour-based** structure of travel where the tour is used as the base unit of modeling travel instead of the elemental trip; this structure preserves a consistency across trips included into the same tour, by such travel dimensions as destination, mode, and time of day.

3. **Micro-simulation** modeling techniques that are applied at the fully-disaggregate level of persons and households, which convert activity and travel related choices from fractional-probability model outcomes into a series of “crisp” decisions among the discrete choices; this method of model implementation results in realistic model outcomes, with output files that look very much like a real travel/activity survey data.

The MORPC model incorporates most of the positive features of the other activity-based and tour-based models as well as the growing body of research on activity-based modeling and micro-simulation. In particular, the structure and application experience of the SFC model [1,2] and NYMTC model [3,4] had been carefully studied before the decisions regarding the MORPC structure was made. Comparing to the predecessors, the MORPC structure represents two significant steps further in a better and more realistic description of travel behavior:

- **Explicit modeling of intra-household interactions and joint travel** that is of crucial importance for realistic modeling of the individual decisions made in the household framework and in particular for choice of the high occupancy vehicle (HOV) as travel mode. The original concept of a “full individual daily pattern” that constituted a core of the previously proposed activity-based model systems [5-8] has been extended in the MORPC system to incorporate various intra-household impacts of different household members on each other, joint participation in activities and travel, and intra-household allocation mechanisms for maintenance activities [9-12].

- **Enhanced temporal resolution of 1 hour with explicit tracking of available time windows** for generation and scheduling of tours instead of the 4-5 broad time-of-day periods applied in most of the conventional and also activity-based models previously developed. The time-of-day choice model adopted for MORPC is essentially a continuous duration
model [13] transformed into a discrete choice form. The enhanced temporal resolution opens a way to explicitly control the person time windows left after scheduling of each tour and use the residual time window as an important explanatory variable for generation and scheduling of the subsequent tours.

The MORPC model system development has been extensively reported on a step-by-step basis with special reports devoted to each main model [14-22]. The current memo gives a general overview of the model system with the emphasis on the most important structural features and linkage across models. The estimation results and values of the coefficients for each model are discussed in detail in the corresponding reports.

2. Data sources and basic inputs

2.1. Travel survey database

The MORPC model was estimated based on the 1999 Household Interview Survey (HIS). The survey collected single weekday travel data from 5,555 households. There were 13,500 full person day observations and almost 18,000 tours for various purposes. Though, the scope and quality of the survey were quite high and allowed for estimation of a set of complicated and highly-segmented activity-based models, there was a problem with estimation of the mode choice model since only about 200 tours (1%) were made by transit (including walk to transit and drive to transit access). To enrich the data set for the mode choice model estimation the HIS was combined with the on-board transit survey.

2.2. Transportation networks

Highway and transit networks are maintained in the TP+ software package. This software is also used for building highway and transit level-of-service skims and for assigning trip tables to transport networks. The MORPC model offers a high level of detail and special resolution for the most parts of the region. There are 1,805 internal traffic analysis zones. Still, for transit modeling each zone has been divided into three transit-access sub-zones (short walk, long walk, and no access) and the corresponding corrections to the skimming procedures were used to create more realistic walk skims for each sub-zone.

There are four network simulation periods currently (AM peak, Midday, PM peak, Night) of which the PM skims can be substituted by transposed AM skims and the NT skims can be substituted by MD skims. However, the developed travel demand model allows for a more detailed processing of TOD periods since the core time-of-day choice model has a temporal resolution of 1 hour and most of the other models use time-of-day specific constants by 7 periods. The correspondence between the network simulation periods, time-of-day periods used in the other models, and the actual temporal resolution of the time-of-day scheduling procedures are shown in the Table 2.1 below. Thus the developed model can support more detailed time-of-day specific simulation procedures as well as create hour-specific matrices for peak hours if needed.
Table 2.1. Correspondence between tour departure/arrival hours and TOD periods

<table>
<thead>
<tr>
<th>Reported departure-from-home / arrival-back-home time</th>
<th>Adjusted tour start / end time</th>
<th>TOD period</th>
<th>Network simulation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earlier than 5:30</td>
<td>5</td>
<td>1</td>
<td>NT</td>
</tr>
<tr>
<td>5:30-6:29</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6:30-7:29</td>
<td>7</td>
<td>2</td>
<td>AM</td>
</tr>
<tr>
<td>7:30-8:29</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8:30-9:29</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9:30-10:29</td>
<td>10</td>
<td>3</td>
<td>MD</td>
</tr>
<tr>
<td>10:30-11:29</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:30-12:29</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12:30-13:29</td>
<td>13</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>13:30-14:29</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:30-15:29</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15:30-16:29</td>
<td>16</td>
<td>5</td>
<td>PM</td>
</tr>
<tr>
<td>16:30-17:29</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17:30-18:29</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:30-19:29</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19:30-20:29</td>
<td>20</td>
<td>6</td>
<td>NT</td>
</tr>
<tr>
<td>20:30-21:29</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21:30-22:29</td>
<td>22</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>22:30 and later</td>
<td>23</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3. Land use and demographic data input

Primary socio-economic data were developed at the traffic analysis zone level. These data included the set of necessary population characteristics used as input to the population synthesis procedure as well as the basic employment data by branches used as input to accessibility and location choice models. The following main data types were provided for each zone and base/target year:

- Population:
  - Total population:
    - Household
    - Non-household (special group quarters)
  - Number of households
  - Total labor force
  - Average household income

- Employment:
  - Office
  - Retail goods
  - Retail service
  - Other

- Enrollment:
  - University/college
  - School (K12)
Based on these data items and combining them with the data from complementary surveys, the following additional data types were calculated:

- Area type
- Average parking rate
- Percentage of transit sub-zones (short walk, long walk, no access) within the zone
- Parking capacity (paid and free)
- Accessibility indices

In the model estimation and application it is assumed that all types of land-use are distributed within a traffic analysis zone by transit access sub-zones according to the same proportion. Area type definitions and average parking rate models were developed based on the densities of the different land-uses.

Accessibility indices have a form of destination-choice log-sums and can be included into the global equilibrium procedure. In the model estimation they are logarithmically transformed to be included into the utility functions because the original variable represents a result of summation of attractions across all destinations weighted by accessibility (exponent of the negative of impedance). They are calculated across destination zone attractions (first for total jobs, reflecting on the work tour accessibility, and then, for retail jobs, reflecting on the non-work tour accessibility). They are additionally stratified by mode (auto, transit, and walk) and time-of-day period (AM peak versus off-peak).

Map shown in the Figure 2.1 below give example of the accessibility indices by zones within the Mid-Ohio region calculated for auto mode in AM peak period (i.e. using congested auto times as the impedance measure that is relevant for most trips to work).

![Figure 2.1. Accessibility to jobs by auto mode in AM peak period](image-url)
2.4. Core models and auxiliary procedures

The MORPC model system represents a complex construct that has a core set of choice models intended to model travel behavior, network simulation procedures, and numerous auxiliary models and procedures that serves the core models providing inputs to them or transforming there outputs. The Figure 2.2 outlines the model system.

![Model system components diagram]

Figure 2.2. Model system components

The following section gives a description of the core set of choice models. Further on, in the section 5 each of the core choice models is described in detail. Population synthesizer is described in the section 4. The other procedures and auxiliary models include the following main components:
• Highway and transit network assignment and base skimming procedures implemented as TP+ macros. They are described in detail in the Model User Manual [23].

• Pre-skimming procedure implemented as TP+ macros that allows to create reasonable highway and transit skims for the first global model iteration as well as for the model estimation. A special procedure has been developed to create preliminary skims for the future years as well in order to speed up global convergence.

• Location attractors that represent size variables for the primary destination choice model and stop-location model. These attractors are calculated as linear combinations of the relevant land-use variables (employment, school enrollment, population). They are specific to each travel purpose and also additionally for stop location they are segmented by direction (outbound, inbound).

• Accessibility measures described in the previous section, that are calculated based on the land-use variables and travel times. These measures may be included into the global equilibrium procedure and updated at each iteration (after each network processing and skimming).

• Additional traffic components not covered by the core demand model; they are modeled externally and added to the corresponding trip tables before assignment:
  o External traffic, that is done by a special set of models that include trip generation and distribution of traffic from and to external zones for each time-of-day period,
  o Heavy and light truck trip tables, that is done by a special model that includes generation and distribution of freight vehicle movements for each time-of-day period

• Free-parking eligibility model applied for each person commuting to the CBD area for mandatory activities. This model “tags” each person as either eligible for free parking in the CBD area or not. This attribute is used in the mode choice model when parking cost component is calculated.

• Parking location model that chooses the actual parking location for each auto trip to the CBD area as a function of the available parking space, parking rate, person characteristics and distance from the trip origin to the parking zone as well as between the parking zone and the destination.
3. The core model system design

The core set of models includes 8 main choice models applied in succession. This set of models, the order of application, and the linkage across them is described in the following sub-section. The other two sub-sections give details on the model segmentation and the time window technique. The last constitute an innovative component of the model system that is intensively used in most of the choice models and frequently referred to in the subsequent sections of the current report.

3.1. Conceptual framework, main choice models and linkage across them

The current generation of activity-based regional travel demand models of which the MORPC model system is a representative, is based on a sequence of discrete choice models applied in a macro-simulation fashion. In the model system design, there always has been a question, what is the better behavioral unit that represents a decision maker for trip (or tour) generation stage – household or person. Conventional travel demand model are mostly household-based (i.e. applied at the entire-household level though any person-related characteristics can be incorporated) while the contemporary activity-based model tend to be person-based (i.e. applied at the individual person level though any household characteristics can be incorporated).

The choice of the decision-making unit (household or person) is less crucial if simple statistical models are applied that link person/household characteristics to the number of generated trips/tours (like conventional regression models for trip production). Conventional trip production models that based on limited market segmentation produce very similar results for both strategies (household-based and person-based) being aggregated at the zonal level while the model outcomes at the individual level are not analyzed. Micro-simulation models that implies more detailed segmentation by household and person types is much more sensitive to the choice of the decision-making unit. Additionally, since ensuring consistency at the individual level is considered as one of the main challenges of the micro-simulation modeling paradigm it is important to find a right balance and linkage between household and person dimensions. Micro-simulation technique opens the way to resolve this issue by means of linked choice models with differential decision making unit (household for some choice dimensions while person for some other once).

It allows for explicit incorporation of intra-household interactions of various types. A significant share of travel-related decision is made within the complicated framework of the entire-household decision-making process, where each person’s preferences are intertwined and consolidated across all household members. As a result some activities are shared among several household members; some other ones are generated at the entire-household level but allocated to particular members to implement; while other activities have a purely individual character.

In the design and development of the MORPC modeling system, the following three-part segmentation of household and person activities proved to be effective and practical to implement at the generation stage and in subsequent choice models:

- **Individual activities**: corresponding tours are generated and scheduled at the person level (with possible inclusion of the household variables, but without direct coordination of choices); the frequency of these activities is modeled for each person either as a part of the daily activity/travel pattern, or by means of the frequency choice model.
• **Allocated activities:** corresponding tours are generated at the entire-household level because they reflect the collective household needs, however they are implemented and scheduled individually; thus a tour-frequency model is formulated and applied for the household, and then it is followed by an intra-household allocation model that is applied for each generated tour and considers household members as alternatives.

• **Joint activities:** corresponding tours are generated at the entire-household level and also implemented by several household members traveling together (and frequently sharing the same activity); a tour-frequency model is formulated and applied for the household, and then it is followed by a person participation models that is applied for each generated tour and considers possible travel parties (formed of the household members) as alternatives.

The activity types and trip purposes are grouped into three main segments:

- **Mandatory** activities (including going to work, university, or school).
- **Maintenance** activities (including shopping, banking, visiting doctor, etc).
- **Discretionary** activities (including social and recreational activities, eating out, etc).

Table 3.1 summarizes the main assumptions made regarding the possible combinations of activity types and settings. Only five out of the nine possible combinations are allowed, which greatly simplifies the modeling system, while preserving behavioral realism and covering most of the observed cases.

<table>
<thead>
<tr>
<th>Activity Type / Travel Purpose</th>
<th>Individual Setting</th>
<th>Allocation Setting</th>
<th>Joint Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Maintenance</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Discretionary</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Travel for mandatory activities is always assumed to have an individual character. Frequency of these activities, location, and scheduling are modeled for each person independently. While household-composition variables are used in the utility functions for these individual activities, there is no explicit linkage across all choices made by different individuals with the notable exception of staying at home together or having a non-mandatory travel day together. This assumption is based on the fact that most of the mandatory activities have fixed frequencies and schedules defined exogenously to the household activity framework; however, a realistic activity-based model should be sensitive to the fact that unscheduled at home activity (child at home sick) will negatively impact the frequency of other mandatory travel.

Maintenance activities may be either allocated or joint. It is assumed that the maintenance function is inherently household-based, even if it is implemented individually or related to a need of a particular household member, like visiting doctor. Even in these cases, maintenance activities are characterized by a significant degree of intra-household coordination, substitution, and possibly sharing.
Discretionary activities may be either individual or joint. It is assumed that these activities are not allocated to household members since they do not directly relate to household needs. Thus, these activities are either planned and implemented together by several household members or are planned and implemented individually.

It is assumed that all else being equal, there is a predetermined structure of preferences in the activity generation and scheduling procedure along both dimensions (activity type and setting). Mandatory activities take precedence over maintenance activities, while maintenance activities take precedence over discretionary activities. Joint activities are considered superior to allocated activities, while allocated activities are in turn considered superior to individual activities. Combination of these two preference principles yields the following order of generation and scheduling activities that serves as the main modeling skeleton for the MORPC model system design:

1. Individual mandatory activities,
2. Joint maintenance activities,
3. Joint discretionary activities,
4. Allocated maintenance activities,
5. Individual discretionary activities.

The structure of the model system follows the conceptual framework described above – see Figure 3.1 below. The numbering of the models 1-8 is not strictly sequential but corresponds to the meaningful “blocks” of which the model stream is built. Some of the models (like for example the TOD choice model 6) are called twice in the procedure – first time for mandatory tours (after the model 2) and second time for non-mandatory tours (after the model 4). Models 5, 6, and 7 are also closely connected by sharing mode choice log-sums, thus they are implemented together for technical convenience and computer time savings.
The modeling system uses synthesized household population and its structural characteristics as a base input. Car ownership model (1) is the first choice model applied, but Individual daily activity-travel pattern type (2) is essentially the first travel model in the modeling hierarchy. It returns the most important features of the travel behavior for each household member and includes exact number and travel purpose for all mandatory tours. The subsequent chain of models (non-mandatory tour generation, destination, time of day, and mode choice, as well as intermediate stop frequency and location choice) is applied conditional upon the chosen daily activity pattern type for each person. Conventional travel demand models normally do not have this component and start with a set of trip generation models segmented by travel purpose. The reason for inclusion of daily activity pattern type as a leading component of the modeling system is that the decisions made by person regarding the frequency of travel tours for different purposes are not independent because of the mutual time-space constraints on daily activity and travel. In particular, the presence of mandatory work activity – usually associated with significant duration and travel time – is a decisive fragment in the daily activity agenda which all other travel/activity decisions are conditional upon. This modeling component ensures integrity of the travel choices modeled for each individual and avoids principal conflicts that otherwise may occur in the model application. (For example, a person with a long work activity duration and commute time will also be assigned several additional tours that could not be implemented within the narrow time window left after the mandatory activity).

Daily activity pattern type includes full information about the frequency of tours made for mandatory purposes (work, university, school) including combinations of them. Thus, in the subsequent modeling stream there is no need in a tour generation model for mandatory purposes.
However, it leaves open the frequency of tours for non-mandatory purposes (maintenance, discretionary), thus, the correspondent models are applied down the modeling hierarchy. Daily activity pattern type choice contains a non-travel option where the person can be engaged in in-home activity only (purposely or because of being sick) or can be out of town. In the model system application, a person who has chosen a non-travel pattern is not considered further in the modeling stream, constituting a saving in technical terms. Daily activity pattern choices of the household members are linked in such a way that decisions made by some members are reflected in the decisions made by the other ones. In particular, child staying at home will positively impact the probability that the adult household members will stay home in order to take care on him/her. Thus, with the application of this model, more behaviorally-realistic travel simulation for each individual and the whole household is obtained.

The next stage defines primary destination, mode, and time-of-day period for each mandatory tour. This stage is placed at this level in the modeling hierarchy because the underlying decisions (workplace, school, starting and ending time of the activity) are mostly person-based and less impacted by the intra-household interaction. Additionally, the scheduling of mandatory activities is generally considered as a higher-priority decision than any decision regarding non-mandatory activity for either the same person or for the other household members. A similar conceptual framework has been adopted in other research works. Bhat and Singh consider a daily activity-travel generation model system for workers where work activity serves as a “peg” on which the whole pattern is built [7]. In particular, work duration and arrival time home proved to be strong discriminators for additional post-home-arrival activity in the MORPC model.

As a result of the mandatory activity scheduling, the residual time windows are calculated for all household member and their overlaps across household members are estimated. Time window overlaps that are left in the daily schedule after the mandatory commitment of the household members have been made, constitute the potential for joint travel resulting from sharing the same activity (maintenance or discretionary) [9]. A person that has chosen a non-mandatory pattern is considered full-time available for joint household travel. As discussed below, there is statistical evidence that a significant share of “day-offs” taken by workers are devoted to major shopping and household arrangement needs that are frequently associated with joint activity and travel.

The third major modeling stage relates to the joint household tour generation (frequency choice). This model produces number of joint tours by travel purpose for the entire household and then defines the participation of each household member in each joint household tour. Joint tours are considered superior in the modeling hierarchy compared to the individual non-mandatory tours, because they require a consolidation effort of several household members.

The next major modeling stage relates to individual maintenance tours that are modeled at the household level and then allocated to the household members conditional upon the frequency of mandatory tours and joint tours in which a person has chosen to participate. It is followed by the stage where individual discretionary tours are generated for each household member.

The next stage relates to the destination, mode, and time-of-day choice for all non-mandatory tours including joint and individual. When assigning destinations and time of day, a fully joint tour is considered as one unit, thus ensuring consistency and a necessary linkage across all household members involved. The last stage relates to the choice of intermediate stop frequency and location. Again, a fully joint tour is considered as a single unit, ensuring consistency of mode and stop-related decisions.
The Table 3.2 below gives an additional summary of the core set of models listing the decision making unit and the outcome (choice) dimensions for each model.

**Table 3.2. Summary of the core set of choice models**

<table>
<thead>
<tr>
<th>Choice model</th>
<th>Decision-making-unit</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Car ownership</td>
<td>Household</td>
<td>No of cars</td>
</tr>
<tr>
<td>2. Daily pattern type</td>
<td>Person</td>
<td>No of mandatory tours, Staying at home</td>
</tr>
<tr>
<td>3. Joint tours</td>
<td>Household, tour, person</td>
<td>No of joint tours, person participation in each tour</td>
</tr>
<tr>
<td>4. Individual non-mandatory tours and sub-tours</td>
<td>Household, tour, person</td>
<td>No of individual tours, allocation to persons</td>
</tr>
<tr>
<td>5. Primary destination</td>
<td>Tour (individual or joint)</td>
<td>Destination zone</td>
</tr>
<tr>
<td>6. Time of day</td>
<td>Tour (individual or joint)</td>
<td>Departure/arrival hours</td>
</tr>
<tr>
<td>7. Entire-tour mode</td>
<td>Tour (individual or joint)</td>
<td>Aggregate mode</td>
</tr>
<tr>
<td>8. Stop frequency, location and trip mode choice</td>
<td>Tour, half-tour, trip</td>
<td>No of stops on each half-tour, location of stops and detailed mode</td>
</tr>
</tbody>
</table>
3.2. Main model dimensions and travel segments

There are several general dimensions for the model segmentation that are basically applied for all relevant models. They include travel purpose, person type, entire-tour mode combination, and trip mode. There are several other segmentations that are pertinent to some specific model only and will be discussed in the corresponding sub-sections of the section 5 below. The general segmentation adopted for the MORPC model system includes the following dimensions:

- **Travel purpose:**
  - Individual mandatory home-based tours:
    - Work/business-related
    - University
    - School
  - Joint non-mandatory home-based tours:
    - Shopping
    - Other maintenance
    - Discretionary
    - Eating out
  - Individual non-mandatory home-based tours:
    - Allocated maintenance tours:
      - Escorting
      - Shopping
      - Other maintenance
    - Individual discretionary tours:
      - Discretionary
      - Eating out
  - At-work sub-tours:
    - Eating out
    - Work/business-related
    - Other (maintenance)

- **Person type:**
  - Worker (18 year old or older)
    - Full-time (40 hours and more)
    - Part-time (less than 40 hours)
  - Non-working adult (18 year old or older)
    - Full-time university student (post-secondary)
    - Non-working and non-studying adult (homemaker/retired/unemployed)
  - Child
    - Preschool (under 6)
    - School pre-driving (6-15)
    - School driving (16-17)

- **Entire-tour mode combination:**
  - SOV
  - HOV (if at least one trip is HOV)
  - Transit with walk access
  - Transit with drive access (P&R, K&R)
  - Non-motorized
  - School bus (for school tours only)
- **Trip mode:**
  - SOV
  - HOV
  - Local bus
  - Express bus
  - Bus rapid transit
  - LRT
  - Commuter rail
  - School bus
  - Non-motorized (walk, bicycle)

- **Area type:**
  - Urban:
    - CBD
    - High density
    - Low density
  - Suburban:
    - High density
    - Low density
  - Rural:
    - Residential
    - Green area

### 3.3. Time window rules

The TOD choice model applied in the model system has a temporal resolution of one hour. This enhanced temporal resolution opens a way to track and schedule explicitly all tours and activities implemented by a person in the course of the day. Moreover, its allows to use residual time windows left after scheduling the mandatory activity or each person, as explanatory variables in the non-mandatory tour generation and scheduling. The following definitions and rules have been accepted for explicit modeling the temporal dimension - see also the **Figure 3.2** below:

- **Full formal window** that includes 19 hours from 5AM to 23PM. All activities before 5AM are shifted to 5. All activities after 23PM are shifted to 23. Tours can be scheduled within the full formal window back to back; however they must not have overlaps or span each other.

- **Tour time-of-day (scheduling)** correspond to the departure from home and arrival back home hour. It includes activity duration and travel time both from home to the activity and from the activity back home as well as all intermediate stops on the way.

- **Active window** includes only 16 hours from 7AM to 22PM (i.e. excludes extremely early or late hours 5, 6, and 23). Activity window is used for calculation of residual time windows and their overlaps as variables fed to the tour generation models. Though tours may be scheduled within the full formal window, the extreme hours are highly infrequent for starting non-mandatory activities. Thus, truncated active window proves to be a better parameter that characterizes person time resources for considering a new activity.

- **Residual person time window** is calculated as the number of hours left open within the active window after scheduling some activities. In the tour generation procedure residual windows are calculated once after scheduling mandatory activities. In the time-of-day...
choice model, residual windows are updated sequentially after scheduling each mandatory or non-mandatory tour and used to generate feasible time-of-day alternatives for the subsequent tour.

- Residual window overlap is calculated as a number of mutual hours left open in the active windows of two persons. Window overlaps represent important measure of potential for joint activity/travel. There are several pair-wise window overlaps specific to person types intensively used in the joint travel model:
  - Maximum pair-wise window overlap across the household adults
  - Maximum pair-wise window overlap across the household children
  - Maximum pair-wise window overlap of the household adults and children
  - Maximum pair-wise window overlap of a particular person with the (other) household adults
  - Maximum pair-wise window overlap of a particular person with the (other) household children

![Figure 3.2. Time window rules](image-url)
4. Population Synthesizer

The Population synthesis procedure is designed to create a list of households in each TAZ with all necessary details regarding the household and person variables used in the travel models and according to the input average zonal characteristics – see Figure 4.1 below.

---

**Controlled variables**

<table>
<thead>
<tr>
<th>Zonal values</th>
<th>Marginal HH distributions</th>
<th>Multi-dimensional HH distributions</th>
<th>PUMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population &amp; HH</td>
<td>By size (1-9)</td>
<td>By size &amp; workers (9x6)</td>
<td>Seed</td>
</tr>
<tr>
<td>Labor Force</td>
<td>By workers (0-5)</td>
<td>By size &amp; income (9x6x3)</td>
<td>Look-up</td>
</tr>
<tr>
<td>HH income</td>
<td>By income (1-3)</td>
<td>By size, workers &amp; income (9x6x3)</td>
<td>Seed</td>
</tr>
</tbody>
</table>

---

**Uncontrolled variables**

<table>
<thead>
<tr>
<th>List of synthetic HHs</th>
<th>List of HH in PUMA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-size</td>
</tr>
<tr>
<td></td>
<td>-income</td>
</tr>
<tr>
<td></td>
<td>-workers</td>
</tr>
<tr>
<td></td>
<td>-full-time workers</td>
</tr>
<tr>
<td></td>
<td>-part-time workers</td>
</tr>
<tr>
<td></td>
<td>-university students</td>
</tr>
<tr>
<td></td>
<td>-non-working adults</td>
</tr>
<tr>
<td></td>
<td>-preschool children</td>
</tr>
<tr>
<td></td>
<td>-school pre-driving children</td>
</tr>
<tr>
<td></td>
<td>-school driving children</td>
</tr>
</tbody>
</table>

Discretizing

---

**Figure 4.1. Population synthesis procedure**

The following input parameters should be specified for each zone for each target year:

- Total population
- Total number of households
- Total labor force
- Average household income

The output is generated as a list of households in each zone with the following characteristics:

- Household income group:
  - Low – less than $30,000
  - Medium $30,000-$74,999
  - High equal of higher than $75,000
- Adult household members (18 years and older)
  - Number of full-time workers (40 or more hours a week)
  - Number of part-time workers (less than 40 hours a week)
- Number of full-time university/college students
- Number of non-working and non-studying adults

- Household children (under 18):
  - Number of preschool children (under 6)
  - Number of school pre-driving-age children (6-15 years old)
  - Number of school driving-age children (16-17 years old)

The population synthesis procedure passes through the following two main stages:

1. Calculation of multidimensional household distribution by controlled variables for which zonal total or averages are given as a part of the socio-economic and land-use development scenario,

2. Conversion of the household distribution to a list of households and addition of uncontrolled variables by matching each synthetic household to the identical household from PUMS.

4.1. Multidimensional household distribution by controlled variables

The following controlled variables are specified:

- Household size (1,2,3,4,5,6,7,8,9+)
- Number of workers (0,1,2,3,4,5+)
- Income group (1,2,3)

First, a marginal distribution of households by size is calculated. The procedure includes the following steps implemented for every zone that has a positive number of households:

- Calculate average household size for each zone as a ratio of the household population to number of households,
- Apply percentage curves to calculate percentage of households for each size category 1,2,3,4,5,6+ in each zone as a function of the average household size
- Extend percentage breakdown for the open 6+ category to 6,7,8,9+ categories for each zone based on the look-up table
- Adjust the distribution 1,2,3,4,5,6,7,8,9+ for each zone to the average household size using the entropy-maximizing method [14].

Second, a marginal distribution of households by number of workers is calculated. The procedure includes the following step implemented for every zone that has a positive number of households:

- Calculate average number of workers per household for each zone as a ratio of the employed labor force to number of households,
- Apply percentage curves to calculate percentage of households for each number-of-workers category 0,1,2,3+ in each zone as a function of the average number of workers per household and zonal shares of households of size 1 and 2 calculated at the previous stage,
- Extend percentage breakdown for the open 3+ category to 3,4,5+ categories for each zone based on the look-up table.
• Adjust the distribution 1,2,3,4,5,+ for each zone to the average number of workers per household using the entropy-maximizing method.

Third, having calculated the marginal distributions of households by size and number of workers the preliminary two-dimensional distribution of households by size and number of workers is calculated for each zone. The procedure includes two stages:

• Prepare seed two-dimensional distribution of households in each PUMA by size 1,2,3,4,5,6,7,8,9+ and number of workers 0,1,2,3+.

• Apply IPF procedure for each zone using zone-specific margins and seed distribution for the corresponding PUMA.

Forth, the marginal distribution of households by income groups in each zone is built in three stages:

• Estimation of the marginal distribution of households by income groups based on the previously constructed two-dimensional distribution of households by size and income applied in combination with the observed income distribution within each size-by-workers cell (look-up table). Advantage of this method is that income distribution is tied to the household-composition mix in each zone. Drawback of this method is that the resulting distribution of households by income is not controlled by the zonal average income forecast.

• Independent estimation of the marginal distribution of households by income groups based on the percentage curves as functions of a ratio of the zonal average income to the regional average income. Advantage of this method is that the resulting distribution of households by income is controlled by the zonal average income forecast income. Drawback of this method is that the distribution is not tied to the household-composition mix in each zone.

• Since the two estimation methods have symmetrical advantages and drawbacks it is proposed to calculate a weighted average of them (each of the three income group shares should be averaged across these two methods) with predetermined weights. The weights are regulated by a parameter “sensitivity to zonal income forecasts” that is scaled between 0 and 1 and represents the weight of the curve-based margins. The complementary value represents a weight for the look-up-based margins. This parameter is defined by a user in the control file.

Having calculated the marginal distributions of households by size, number of workers, and income group, the final three-dimensional distribution of households by size, number of workers, and income is calculated for each zone. The procedure includes two stages:

• Prepare seed three-dimensional distribution of households in each PUMA by size 1,2,3,4,5,6,7,8,9+, number of workers 0,1,2,3,4,5+, and income group (1,2,3),

• Apply IPF procedure for each zone using zone-specific margins and seed distribution for the corresponding PUMA.

4.2. Conversion to a list of households and addition of uncontrolled variables
Three-dimensional distribution of households in each zone by household size, number of workers, and income group is converted into the list of households according to the following procedure:

- Household distribution in each zone is multiplied by the total number of households and the resulting array of fractional numbers is discretized using the method described in [14],

- List of households is created for each zone by replicating each household type (feasible combination of size, number of workers, and income category) according to the discrete number in the corresponding cell of the zonal distribution.

Then the uncontrolled variables are added by looking up similar households from PUMS which correspond to values in the three controlled dimensions. The following procedure is applied:

- A list of sampled households is prepared in each PUMA. The preparation includes calculation of the three controlled variables and seven uncontrolled variables:
  
  o Controlled variables:
    1. Household size (truncated by 9+)
    2. Number of workers (truncated by 5+)
    3. Household income group (low, medium, high).
  
  o Uncontrolled variables:
    1. Number of full-time workers
    2. Number of part-time workers
    3. Number of university students
    4. Number of non-working adults
    5. Number of preschool children
    6. Number of school children of pre-driving age
    7. Number of school children of driving age

- For each zone and synthetic household proceed sequentially, a household from the corresponding PUMA is randomly chosen. The algorithm is as follows:
  
  1. Define all households in PUMS as available
  2. Take the first zone
  3. Take the first synthetic household
  4. Find an available household from the corresponding PUMA with the same controlled variables.

    a. If successful, write the uncontrolled variables to the synthetic household and make the source PUMS household unavailable. If the actual PUMS household size is larger than 9 or the actual number of workers is larger than 5 re-set the controlled variables (household size and number of workers) of the synthetic household accordingly.

    b. If unsuccessful, but there are unavailable households that match the synthetic household, then make all households of this PUMA and this type (size*workers*income) available and go to 4.a
c. If unsuccessful and there is no unavailable household of this type in the PUMA, then change household size by -1 and number of workers by -1 (if adjusted household size is large than number of workers), mark this synthetic household as “adjusted” and go to 4.a

5. Take the next synthetic household and go to 4; if the list of households in the zone is up, then go to the next zone

6. If the next zone is valid, go to 3. If the list of zones is up, go to end.

A detailed description of the population synthesizer can be found in the corresponding technical report [14].
5. Description of main travel models

Each of the main travel demand models 1-8 is described below in more detail. The formal description includes the following main structural components of the models:

- **Decision-making unit**, i.e. the unit for which the choice is applied. Depending on the choice model, it may be a household, person, tour, half-tour, travel party associated with a join tour, etc.

- **Segmentation**, i.e. travel and person characteristics that are so important to the corresponding choices that the model structure and/or coefficients should be estimated fully or at least partially specific to each segment.

- **Choice alternatives** considered within the model framework that represent possible outcomes of the travel decisions. Each model is associated with choice of one alternative out of the available set made by (or for) the decision-making unit. Several of the choice models include special availability rules that constrain the set available for each decision-making unit in each particular situation.

- **Main explanatory variables** included in the utility function. The variables are divided into two main groups:
  - Household, person, zonal and other fixed characteristics that are not dependent on the other modeled choices made upward or downward the model system hierarchy. Most of these variables and the way they are used are similar to the conventional model systems.
  - Variables that represent outcomes of the other choice models. These variables create explicit linkage across various travel dimensions and ensure behavior realism of the entire model system outcome. Most of these variables are specific to the micro-simulation modeling technique and cannot be applied in the conventional model framework. Three specific groups of variables can be distinguished within this category:
    - Outcomes of the upper-level models upon which the lower-level models are conditional. For example, the car ownership model specifies a number of cars for each household that is intensively used further as an explanatory variable in many models down the choice hierarchy. These variables ensures a “downward vertical integrity” of the model system.
    - Outcomes of the models of the same hierarchical level that are used according to a predetermined order of processing segments. For example, the chosen daily activity patterns for children have a strong impact on the daily activity patterns of the adult household members. These variables ensure a “horizontal integrity” of the model system.
    - Outcomes of the lower-level models in a form of the composite log-sums that are used as variables for upper-level choices. For example, tour mode choice log-sum serves as an important variable in the primary destination choice model. These variables ensure an “upward vertical integrity” of the model system.
5.1. Household Car Ownership Model

The car ownership model is based on the concept of relative car sufficiency as the main explanatory variable. Relative car sufficiency is calculated as a number of cars minus number of adults according to the Table 5.1 below. By definition, car sufficiency is differential across choice alternatives for the same household.

Table 5.1. Relative car sufficiency

<table>
<thead>
<tr>
<th>No. of adults</th>
<th>Car-ownership alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>-2</td>
</tr>
<tr>
<td>3</td>
<td>-3</td>
</tr>
<tr>
<td>4</td>
<td>-4</td>
</tr>
</tbody>
</table>

Car sufficiency variables are applied each in the correspondent utility. For example, car sufficiency relating to the zero-car alternative is applied in the zero-car (first) utility. It is assumed that alternatives with negative car sufficiency (i.e. shortage of cars versus the number of workers or adults) should be less frequently observed, all else being equal. On the other hand, alternatives with positive car sufficiency (especially with a large surplus of cars) should also be discouraged because surplus cars cannot be really used by the household. Below is a list of the formal structural features of the car ownership choice model.

Unit: Household  
Segmentation: No segmentation

Choice alternatives (5):
- No cars,
- 1 car,
- 2 cars,
- 3 cars,
- 4+ cars

Main explanatory variables:
- Relative car sufficiency for the household adults for each alternative:
  - Car surplus (no of cars over adults),
  - Car shortage (no of adults over cars),
- Household size and composition:
  - No of workers
  - Presence of a driving-age child
  - Presence of a preschool child
- Household income
- Residential area type
- Accessibility indices:
  - Transit accessibility to jobs
  - Walk accessibility to jobs

A detailed description of the household car ownership model, relevant statistical data, and the estimation results can be found in the corresponding technical report [15].
5.2. Individual Daily Activity Pattern Type Model

The classification of daily activity patterns (DAP) can be done in many different ways \([5-8]\). DAP definition normally includes a list of activities undertaken by the person in the course of entire day with some predetermined hierarchy of the activity types. DAP may also include activity sequencing / scheduling attributes, as well as travel related characteristics. In particular, the definition proposed by Bowman & Ben-Akiva used the travel tour as a basic unit \([5-6]\). A similar approach has been adopted for the MORPC model system with several modifications in order to account for intra-household interactions of different types.

**Figure 5.1** below shows the structural dimensions along which DAPs are classified in the current structure. The current modeling system designed for MORPC employs only two upper levels of the structure. However, in the future, additional dimensions can be added.

![Classification of daily activity patterns](image)

**Figure 5.1.** Classification of daily activity patterns

DAP is classified by three main categories:

- **Mandatory pattern** that includes at least one of the three mandatory activities – work, university, or school. This constitutes either a workday or a university/school day, and may include additional non-mandatory activities such as separate home-based tours or intermediate stops on the mandatory tours.
• **Non-mandatory pattern** that includes only maintenance and discretionary tours. By virtue of the tour primary purpose definition, maintenance and discretionary tours cannot include travel for mandatory activities.

• **At-home pattern** that includes only in-home activities. At the current stage of model development, at-home patterns are not distinguished by any specific activity (work at home, take care of child, being sick, etc). It should be noted that for simplicity, cases with complete absence from town (business travel) were combined with this category.

Further on in the modeling system, mandatory DAPs are classified by purpose and frequency of mandatory tours. The nature of mandatory activities, that are usually associated with both long duration and long commuting times, limits significantly the number of mandatory tours that can be implemented in the course of a day. The vast majority of observed cases include only one or two tours, where two-tour combinations include either two tours to the same primary activity or a combination of work and university/school activities.

In contrast to the mandatory DAP type, the non-mandatory DAP type includes a wider variety of tour frequencies and purposes that is difficult to cover by one choice framework. Thus, the associated details are modeled later in the model stream by a set of tour-generation models.

The important feature of the proposed DAP model is a linkage across household members. While at the stage of statistical analysis and model estimation, any sort of cross-linkages can be explored, in the application stream of the adopted choice models there must be a “non-cycling” chain of choices according to a predetermined order of person types. Relatively “independent” person types should be processed first, while the more “dependent” person categories should follow them and take the choices made by the previously modeled persons into account when making their own decisions. Adults are generally considered more independent than children, but in this modeling framework, the question is if adults change their behavior based on their children’s DAPs or if the causality the other way around. The most common interaction is if a child stays home, due to sickness or some other reason, at least one adult is likely to change his or her DAP. Thus, in this case adults are “dependent” on children. The proposed sequence of person categories and the corresponding rules of linkage are shown in a schematic way in Figure 5.2.
If there are several household members of the same person category, they all have the same utility, and in the model application they are processed sequentially according to the initially assigned order.

Most intra-household impacts relate to the sharing of non-mandatory activities. In this context, it is important to make a distinction between in-home activities and out-of-home activities. It is also important to distinguish the impact of children on adults (stemming from the child care function) from the cross-impact across adults themselves. Thus, the following four basic intra-household impacts are analyzed:

1. **Child care at home.** If at least one of the preschool or school children stays at home, then at least one of the household adults might also stay at home to take care on the child. In the order of modeling adult household members, workers come first.

2. **Escorting child for non-mandatory activity.** It is assumed that if a non-mandatory pattern has been chosen for a child on a regular workday, it is most frequently associated with visiting the doctor, out-of-home family event, sports event, etc; thus it may require escorting by an adult family member. Thus, in order to take into account a probable time conflict with the mandatory activity, these adults should also have a non-mandatory DAP.

3. **Sharing in-home non-mandatory activity by adults.** If at least one of the household adult members stays at home (or is absent, travels out of town, has a vacation) there is a probability for the other adult household members to join him/her. Thus, the at-home/absent utility for each subsequently modeled adult person category includes an indicator of the staying at home for the previously modeled adults.
4. *Sharing out-of-home non-mandatory activity by workers and students.* If at least one of the household adult members with mandatory commitment has chosen a non-mandatory DAP (day-off for major shopping, vacation, family event) there is a probability for the other adult household members to join him/her. Thus, the non-mandatory utility for each subsequently modeled adult person category, should include an indicator of non-mandatory DAP for the previously modeled adults. Non-working adults may be excluded from this chain of impacts because they predominantly have a non-mandatory DAP.

Below is a list of the formal structural features of the daily activity pattern type choice model.

**Unit:** Person  
**Segmentation:** Full segmentation of the model by 7 person types  
**Choice alternatives (11):**
- Work day  
  - 1 work tour (not available for preschool children)  
  - 2 work tours (not available for children)  
  - Work and university tours (available for workers only)  
- University day  
  - 1 university tour (not available for children)  
  - 2 university tours (available for university students only)  
  - University and work tours (available for university students only)  
- School day  
  - 1 school tour (available for children only)  
  - 2 school tours (available for school children only)  
  - School and work tours (available for school children only)  
- Non-mandatory out-of-home activity  
- Full day at home / absent  

**Main explanatory variables:**
- Household size and composition  
  - Number/presence of full-time workers  
  - Number/presence of part-time workers  
  - Number/presence of non-working adults  
  - Number/presence of university students  
  - Presence of a preschool child,  
  - Presence of a school pre-driving-age child  
  - Presence of a school driving-age child  
- Household income  
- Car ownership/sufficiency  
- Residential area type  
- Accessibility indices:  
  - Auto accessibility to jobs  
  - Walk accessibility to jobs  
  - Walk accessibility to retail attractions  
- Activity patterns chosen by the other household members (modeled prior to the person):  
  - Preschool child at home / with non-mandatory pattern  
  - School pre-driving-age child at home / with non-mandatory pattern  
  - School driving-age child at home / with non-mandatory pattern
- University student at home / with non-mandatory pattern
- Full-time worker at home / with non-mandatory pattern
- Part-time worker at home / with non-mandatory pattern
- Non-working adult at home / with non-mandatory pattern

A detailed description of the daily activity pattern type model, relevant statistical data, and the estimation results can be found in the corresponding technical report [16].
5.3. Joint Travel Generation Model

The joint travel types modeled explicitly in the current system are limited to fully joint tours generated by shared non-mandatory activity of several household members. One of the difficulties in modeling joint travel is that it is necessary not only to predict a number of joint tours, but also link them to the appropriate household members and ensure generation and scheduling consistency between the joint and individual tours of each household member. It is implemented by means of a sequence of 3 choice sub-models - see Figure 5.3 below:

- **Frequency choice**, that returns a number of joint tours generated by a household,
- **Travel party composition** in terms of person categories participating in each tour (adults, children, mixed),
- **Person participation** in each tour for each of the household members.

![Figure 5.3. Structure of the joint travel generation model](image)

Generation of joint travel is basically an entire-household function, thus the tour-frequency model comes first and is applied at the household level. In order to link joint travel to the persons in the household, another two models – travel party composition and person participation – are then applied. It has been found effective to decompose person assignment for joint travel into these two models, because the formulation of a single model that distributes household members by joint tours proved to be too complicated. A travel party composition model allows for narrowing down a subset of household members relevant for each joint travel category, thus making the subsequent person participation model operational.
Participation choice is modeled for each person sequentially. In this approach, only a binary choice model is estimated for each activity, party composition and person type. Quantitatively different alternatives by party size are not distinguished explicitly. A sequence of binary choices is applied for all relevant household members assuming a single possible participation for each person. This approach makes travel party size automatically linked to the household size and composition. For example, the more children in the household, the more likely a bigger travel party will occur for the relevant joint travel where children are in the party composition. For example, the more children are in the household the more likely a bigger travel party will occur for the relevant joint travel where children are in the party composition. A failure to form a travel party in the model application can be resolved by re-starting the Monte-Carlo simulation until the suitable travel party has been formed – see Figure 5.4 as an example for a household including 2 adults and 2 children.

![Diagram](image)

**Figure 5.4.** Application of the person participation model

A detailed description of the joint travel model, relevant statistical data and the estimation results can be found in the corresponding technical report [17] and also in the paper [9]. Below is the short description of the main structural features for each of the 3 sub-models.

### 5.3.1. Joint Tour Frequency Model

**Unit:** Household  
**Segmentation:** Full segmentation of alternative specific constants by travel purpose combinations, partial segmentation of the other coefficients by travel purpose

**Choice alternatives (15):**
- No fully joint tours
• 1 fully joint tour (available only for households with at least 2 persons not staying at home of which at least one is not a preschool child):
  o Shopping
  o Other maintenance
  o Discretionary
  o Eating out

• 2 fully joint tours (available only for households with at least 2 persons not staying at home of which at least one is not a preschool child):
  o Shopping / Shopping
  o Shopping / Other maintenance
  o Shopping / Discretionary
  o Shopping / Eating out
  o Other maintenance / Other maintenance
  o Other maintenance / Discretionary
  o Other maintenance / Eating out
  o Discretionary / Discretionary
  o Discretionary / Eating out
  o Eating out / Eating out

**Main explanatory variables:**

• **Household size and composition**
  o Number of full-time workers
  o Number of part-time workers
  o Number of university students
  o Number of non-working adults
  o Number of preschool children
  o Number of school pre-driving-age children
  o Number of school driving-age children
  o Large household dummy (4 and more persons)

• **Household income**
• **Car ownership/sufficiency**
• **Residential area type**
• **Logged size variable including maximum pair-wise overlaps of residual windows:**
  o Adult with adult
  o Adult with child
5.3.2. Travel Party Composition Choice Model

Unit: Fully joint tour for non-mandatory purpose
Segmentation: Partial segmentation of alternative-specific constants by travel purpose

Choice alternatives (3):
- Travel party including adults only (available only for households with at least 2 adults not staying at home)
- Travel party including children only (available only for households with at least 2 children not staying at home)
- Mixed travel party including at least one adult and at least one child (available only for households with at least 1 adult not staying at home and at least 1 child not staying at home)

Main explanatory variables:
- Household size and composition
  - Number of full-time workers
  - Number of part-time workers
  - Number of university students
  - Number of non-working adults
  - Number of preschool children
  - Number of school pre-driving-age children
  - Number of school driving-age children
- Household income
- Car ownership/sufficiency
- Residential area type
- Logged size variable including maximum pair-wise overlaps of residual windows:
  - Adult with adult (for the adult party alternative)
  - Child with child (for the children party alternative)
  - Adult with child (for the mixed party alternative)
5.3.3. Person Participation in Joint Tours Choice Model

Unit: Possible person-by-tour & travel party combination. It includes each joint tour listed in combination with each household member suitable for the travel party and not staying at home

Segmentation: Partial segmentation of alternative-specific constants by person type in combination with travel purpose and party composition; partial segmentation of income, car ownership, area type, and other coefficients by aggregate person type (adult, child)

Choice alternatives (3):
- Participate in the joint tour; not available in the following cases:
  - Persons with staying at home daily pattern type
  - Persons not suitable for the chosen travel party, like children for adult parties or adults for children parties
- Not to participate in the joint tour; not available for persons whose participation is mandatory to implement the tour:
  - Only 2 adults in the household not staying at home for the adult party
  - Only 2 children in the household (of which one is not a preschool child) not staying at home for the children party
  - The only adult in the household not staying at home for the mixed party
  - The only child in the household not staying at home for the mixed party

Main explanatory variables:
- Presence of “competing” persons of the same type in the household that can participate in the same party
  - Number of other adults in the household if the modeled person is adult
  - Number of other children in the household if the modeled person is child
- Household income
- Car ownership/sufficiency
- Residential area type
- Total number of joint tours implemented by the household
- Logged size variable including maximum pair-wise overlaps of residual windows:
  - The modeled adult with the other adults (for the adult party)
  - The modeled child with the other children (for the children party)
  - The modeled adult with children (for the mixed party)
  - The modeled child with adults (for the mixed party)
5.4. Individual Non-Mandatory Travel Generation Model

The individual tour generation model for non-mandatory activity includes 4 choice sub-models applied successively – see Figure 5.5 below:

- Sub-model for individual tours for household maintenance activities allocated to the household members; though these tours are implemented individually the basic need in this activity relates to the entire household. This model is in turn subdivided into two successively applied sub-models:
  - Household tour frequency choice sub-model for maintenance activities implemented individually
  - Model for allocation of maintenance tours to the household members

- Sub-model for individual tours for personal discretionary activities; it is assumed that these activities are generated and scheduled at the person level without significant interaction among household members (recall that joint tours generated by shared discretionary activity of several household members are modeled before in the model stream).

- Model for non-home-based sub-tours at work.

![Figure 5.5. Individual non-mandatory model structure](image)

Individual tours generated by allocated maintenance activities are modeled first for each person conditional upon the chosen daily pattern and participation in joint household tours. Since these activities are generated by the entire household and then allocated to particular members, it is important to follow an underlying intra-household allocation process.
Individual tours for personal discretionary activities are modeled next because they normally have a lower priority in scheduling. Intra-household linkage is less important at this stage. Person availability in terms of time window left after scheduling the mandatory activities, joint activities, and allocated activities becomes the most crucial determinant.

Work-based sub-tours are modeled last. They are relevant only for those persons who implement at least one work tour. These underlying activities are mostly individual (business-related and eating-out purposes), but may include some household maintenance functions as well that are linked to the person and entire-household maintenance tasks.

Preschool children are not considered in the individual tour model as potential tour makers since they normally do not travel by themselves. However, presence of preschool children as well as their chosen daily activity patterns (for example, going to kindergarten instead of staying at home because of sickness) is included as an important explanatory variable for the other household members. Additionally persons who have chosen a stay-at-home daily pattern are also excluded since they do not travel.

A detailed description of the individual non-mandatory travel model, the relevant statistical data and estimation results can be found in the corresponding technical report [18]. Below is the short description of the main structural features for each of the 4 sub-models.

5.4.1. Individual Maintenance Tour Frequency Choice Model

**Unit:** Household

**Segmentation:** Full segmentation of alternative-specific constants by travel purpose combinations, partial segmentation of the other coefficients by travel purpose

**Choice alternatives (36 combinations of 0,1,2 escorting tours with 0,1,2 shopping tours and with 0,1,2,3 other maintenance tours):**

- No escorting tour, no shopping tour, no other maintenance tour
- No escorting tour, no shopping tour, 1 other maintenance tour
- No escorting tour, no shopping tour, 2 other maintenance tours
- No escorting tour, no shopping tour, 3 other maintenance tours
- No escorting tour, 1 shopping tour, no other maintenance tour
- No escorting tour, 1 shopping tour, 1 other maintenance tour
- No escorting tour, 1 shopping tour, 2 other maintenance tours
- No escorting tour, 1 shopping tour, 3 other maintenance tours
- No escorting tour, 2 shopping tour, no other maintenance tour
- No escorting tour, 2 shopping tour, 1 other maintenance tour
- No escorting tour, 2 shopping tour, 2 other maintenance tours
- No escorting tour, 2 shopping tour, 3 other maintenance tours
- 1 escorting tour, no shopping tour, no other maintenance tour
- 1 escorting tour, no shopping tour, 1 other maintenance tour
- 1 escorting tour, no shopping tour, 2 other maintenance tours
- 1 escorting tour, no shopping tour, 3 other maintenance tours
- 1 escorting tour, 1 shopping tour, no other maintenance tour
- 1 escorting tour, 1 shopping tour, 1 other maintenance tour
- 1 escorting tour, 1 shopping tour, 2 other maintenance tours
- 1 escorting tour, 1 shopping tour, 3 other maintenance tours
- 1 escorting tour, 2 shopping tour, no other maintenance tour
- 1 escorting tour, 2 shopping tour, 1 other maintenance tour
- 1 escorting tour, 2 shopping tour, 2 other maintenance tours
- 1 escorting tour, 2 shopping tour, 3 other maintenance tours
- 1 escorting tour, 3 shopping tour, no other maintenance tour
- 1 escorting tour, 3 shopping tour, 1 other maintenance tour
- 1 escorting tour, 3 shopping tour, 2 other maintenance tours
- 1 escorting tour, 3 shopping tour, 3 other maintenance tours
- 1 escorting tour, 4 shopping tour, no other maintenance tour
- 1 escorting tour, 4 shopping tour, 1 other maintenance tour
- 1 escorting tour, 4 shopping tour, 2 other maintenance tours
- 1 escorting tour, 4 shopping tour, 3 other maintenance tours
- 1 escorting tour, 5 shopping tour, no other maintenance tour
- 1 escorting tour, 5 shopping tour, 1 other maintenance tour
- 1 escorting tour, 5 shopping tour, 2 other maintenance tours
- 1 escorting tour, 5 shopping tour, 3 other maintenance tours
- 1 escorting tour, 6 shopping tour, no other maintenance tour
- 1 escorting tour, 6 shopping tour, 1 other maintenance tour
- 1 escorting tour, 6 shopping tour, 2 other maintenance tours
- 1 escorting tour, 6 shopping tour, 3 other maintenance tours
- 1 escorting tour, 7 shopping tour, no other maintenance tour
- 1 escorting tour, 7 shopping tour, 1 other maintenance tour
- 1 escorting tour, 7 shopping tour, 2 other maintenance tours
- 1 escorting tour, 7 shopping tour, 3 other maintenance tours
- 1 escorting tour, 8 shopping tour, no other maintenance tour
- 1 escorting tour, 8 shopping tour, 1 other maintenance tour
- 1 escorting tour, 8 shopping tour, 2 other maintenance tours
- 1 escorting tour, 8 shopping tour, 3 other maintenance tours
• 1 escorting tour, 1 shopping tour, 2 other maintenance tours
• 1 escorting tour, 1 shopping tour, 3 other maintenance tours
• 1 escorting tour, 2 shopping tour, no other maintenance tour
• 1 escorting tour, 2 shopping tour, 1 other maintenance tour
• 1 escorting tour, 2 shopping tour, 2 other maintenance tours
• 1 escorting tour, 2 shopping tour, 3 other maintenance tours
• 2 escorting tours, no shopping tour, no other maintenance tour
• 2 escorting tours, no shopping tour, 1 other maintenance tour
• 2 escorting tours, no shopping tour, 2 other maintenance tours
• 2 escorting tours, no shopping tour, 3 other maintenance tours
• 2 escorting tours, 1 shopping tour, no other maintenance tour
• 2 escorting tours, 1 shopping tour, 1 other maintenance tour
• 2 escorting tours, 1 shopping tour, 2 other maintenance tours
• 2 escorting tours, 1 shopping tour, 3 other maintenance tours
• 2 escorting tours, 2 shopping tour, no other maintenance tour
• 2 escorting tours, 2 shopping tour, 1 other maintenance tour
• 2 escorting tours, 2 shopping tour, 2 other maintenance tours
• 2 escorting tours, 2 shopping tour, 3 other maintenance tours

Main explanatory variables:
• Household size and composition
  o Number of full-time workers
  o Presence of a part-time worker
  o Presence of a university student
  o Presence of a non-working adult
  o Presence of a school driving-age child
  o Total number of preschool and school pre-driving-age children
  o 1-person household dummy
• Household income
• Car ownership/sufficiency
• Accessibility indices:
  o Auto accessibility to retail attractions
  o Transit accessibility to retail attractions
  o Walk accessibility to retail attractions
• Logged maximum residual windows:
  o Across household adults
  o Across household children
• Joint tours implemented by the household:
  o At least one shopping tour
  o At least one maintenance tour
  o At least one eating-out tour
• Activity patterns chosen by the household members:
  o Preschool or school pre-driving-age child at home
  o University student at home
  o Full-time worker at home
  o Part-time worker at home
  o Non-working adult at home
5.4.2. Individual Maintenance Tour Allocation Model

Unit: Individual maintenance tour
Segmentation: Full segmentation of alternative-specific constants by travel purpose

Choice alternatives (all household members of 6 person types excluding preschool children and those who have chosen stay-at-home pattern):

- Full-time workers not staying at home for the whole day
- Part-time workers not staying at home for the whole day
- University students not staying at home for the whole day
- Non-working adults not staying at home for the whole day
- School pre-driving age children not staying at home for the whole day
- School driving age children not staying at home for the whole day

Main explanatory variables:

- Person characteristics:
  - Logged residual time window
  - Non-mandatory daily pattern type dummy
  - No of joint tour participations
- Household income
- Car ownership/sufficiency
- Residential area type
- Transit accessibility to retail attractions
- Activity patterns combinations chosen by the household members:
  - Preschool or school pre-driving-age child staying at home with other adult
  - Preschool or school pre-driving-age child staying at home alone
5.4.3. Individual Discretionary Tour Frequency Choice Model

Unit: Person, excluding preschool children and those who have chosen a stay-at-home pattern

Segmentation: Full segmentation of the model by 3 aggregate person types (workers & university students, non-working adults, and children); full segmentation of alternative-specific constants by travel purpose combination and 6 detail person types, partial segmentation of the other coefficients by travel purpose

Choice alternatives (5):
- No individual discretionary or eating-out tours (not available for those who had chosen the non-mandatory travel pattern but was not assigned any joint or individual tour by the subsequent models applied before the current stage)
- 1 individual discretionary tour
- 2 individual discretionary tours
- 1 individual eating-out tour
- 1 discretionary tour, 1 eating-out tour

Main explanatory variables:
- Person characteristics:
  - Logged residual time window
  - Joint tour participations:
    - At least one joint shopping tour
    - At least one joint other maintenance tour
    - At least one joint discretionary tour
    - At least one joint eating-out tour
- Household composition:
  - Presence of a full-time worker other than the modeled person
  - Presence of a part-time worker other than the modeled person
  - Presence of a university student other than the modeled person
  - Presence of a non-working adult other than the modeled person
  - Presence of a school driving-age child other than the modeled person
  - No of school pre-driving-age children
  - No of preschool children
  - Presence of two or more non-working adults (older household)
- Household income
- Car ownership/sufficiency
- Residential area type
- Accessibility indices:
  - Transit accessibility to retail attractions
  - Walk accessibility to retail attractions
- Activity patterns chosen by the other household members:
  - Preschool or school pre-driving-age child staying at home
  - Full-time worker staying at home
  - Part time worker staying at home
  - Non-working adult staying at home
  - University student staying at home
5.4.4. Work-Based Sub-tour Frequency Choice Model

Unit: Work tour
Segmentation: Full segmentation of alternative-specific constants by travel purpose combination and 2 aggregate person types (full-time worker vs. the other types), partial segmentation of the other coefficients by travel purpose

Choice alternatives (6):
- No at-work sub-tours
- 1 at-work sub-tour for eating out
- 1 at-work sub-tour for business-related purpose
- 1 at-work sub-tour for other (maintenance) purpose
- 2 at-work sub-tours for business-related purpose
- 1 eating-out sub-tour, 1 business-related sub-tour

Main explanatory variables:
- Work tour characteristics:
  - Work tour duration
  - Drive-alone mode dummy
- Person characteristics:
  - 2 work tours dummy
  - Joint tour participations:
    - At least one joint shopping/maintenance/eating-out tour
    - At least one joint discretionary tour
  - Individual non-mandatory tours:
    - At least one escorting/shopping/other maintenance tour
    - At least one discretionary tour
    - At least one eating-out tour
- Household income
- Zero car ownership
- Workplace area type
- Accessibility indices from the workplace:
  - Auto accessibility to retail attractions
  - Walk accessibility to retail attractions
- Activity patterns chosen by the other household members:
  - Full-time worker with non-mandatory pattern
  - Part time worker with non-mandatory pattern
  - University student with non-mandatory pattern
5.5. Primary Destination Choice Model

A detailed description of the primary destination choice model, the relevant statistical data, estimation results, and the sampling procedures applied in both estimation and application of the model can be found in the corresponding technical report [19]. Below is the short description of the main structural features of the model.

**Unit:** Home-based tour (individual or fully joint); work-based sub-tour  
**Segmentation:** Full segmentation by travel purpose, individual/joint setting, and segmenting out work-based sub-tours; partial segmentation of coefficients by person type (travel party for joint tours)  
**Choice alternatives (5,415):** 1,805 TAZs with subdivision by 3 transit accessibility zones; sub-zones with zero size variable are not available.

**Main explanatory variables:**
- Logged sub-zonal size (attraction) variable, calculated as a linear combination of the relevant land-use variables for each travel purpose; work attractions (scaled jobs) are specific and fully segmented by 3 income categories; work-based sub-tour coefficients for size variables are segmented by purpose  
- Travel impedance components:
  - Full bi-directional mode choice log-sum for the representative combination of outbound and inbound time-of-day periods:
    - AM/PM for work tours; segmented by worker status (full-time, part-time) and income  
    - AM/MD for university tours  
    - AM/MD for the 1st school tour  
    - MD/MD for the 2nd school tour  
    - MD/MD for escorting tours  
    - MD/MD for other individual and joint non-mandatory tours if the person daily pattern is (or all patterns for the members of the joint party are) non-mandatory  
    - PM/NT for other individual and joint non-mandatory tours if the person daily pattern (or at least one pattern of the members of the joint party) is mandatory  
    - MD/MD for work-based sub-tours segmented by purpose and full-time vs. part-time
  - Highway distance (MD skim) segmented by aggregate person type (adult, child) for individual tours, travel party composition (adults, children, mixed) for joint tours, and purpose and worker status (full-time, part-time) for work-based sub-tours  
  - Squared highway distance segmented in the same way (coefficients are not estimated and reserved for the aggregate model calibration to match the observed trip length distribution for each segment)
- Statutory border crossing (intra-county dummy for university tours, intra-district dummy for school tours)  
- Combinations of origin (residential) and destination area types:
  - Urban origin / urban destination  
  - Urban origin / suburban destination
• Urban origin / rural destination
• Suburban origin / urban destination
• Suburban origin / suburban destination
• Suburban origin / rural destination
• Rural origin / urban destination
• Rural origin / suburban destination
• Rural origin / rural destination

- Transit accessibility for low car ownership/sufficiency households and persons with low car availability:
  - Zero car ownership:
    - Short walk access at the origin, short walk access at the destination
    - Short walk access at the origin, long walk access at the destination
  - Cars fewer than workers (low car availability for workers):
    - Short walk access at the origin, short walk access at the destination
    - Short walk access at the origin, long walk access at the destination
  - Cars fewer than workers and students (low car availability for students):
    - Short walk access at the origin, short walk access at the destination
    - Short walk access at the origin, long walk access at the destination
  - Cars fewer than adults (low car availability for non-working adults):
    - Short walk access at the origin, short walk access at the destination
    - Short walk access at the origin, long walk access at the destination
  - Cars fewer than adults and school driving-age children (low car availability for driving age children):
    - Short walk access at the origin, short walk access at the destination
    - Short walk access at the origin, long walk access at the destination

- The chosen mode for the work tour (SOV or not) for work-based sub-tours
- Child is staying at home and distance is less than 3 miles:
  - Pre-school child
  - School pre-driving-age child
5.6. Time-of-Day (Tour Scheduling) Model

The proposed time of day model is essentially a discrete choice construct that operates with tour departure-from-home and arrival-back-home time combinations as alternatives. The proposed utility structure that is based on “continuous shift” variables represents an analytical hybrid that combines the advantages of a discrete choice structure (easy to estimate and apply) with advantages of a duration model (parsimonious structure with a few parameters that support any level of temporal resolution including continuous time). The hybrid model currently has a temporal resolution of 1 hour that is expressed in 190 hour-by-hour departure-arrival time alternatives. It does not bring any computational burden at either estimation or application stage and requires only a limited set of coefficients to be estimated using standard discrete choice software.

The model is applied sequentially for all tours in the individual daily activity-travel pattern according to predetermined priority of each activity type. The enhanced temporal resolution allows for applying direct availability rules for each subsequently scheduled tour to be placed in the residual time window left after scheduling the tours of higher priority. This ensures a full consistency for the whole individual daily schedule. The tour hierarchy for scheduling is shown in the Table 5.2 below.

<table>
<thead>
<tr>
<th>Priority (from highest to lowest)</th>
<th>Workers and non-workers</th>
<th>University students and school children</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Work</td>
<td>University/School</td>
</tr>
<tr>
<td>2</td>
<td>University</td>
<td>Work</td>
</tr>
<tr>
<td>3</td>
<td>Maintenance Joint</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Shopping Joint</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Discretionary Joint</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Eating-out Joint</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Escorting individual (allocated)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Shopping individual (allocated)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Maintenance individual (allocated)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Discretionary individual</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Eating-out individual</td>
<td></td>
</tr>
</tbody>
</table>

A detailed description of the time-of-day choice model, the relevant statistical data and estimation results can be found in the corresponding technical report [20]. Below is the short description of the main structural features of the model.

**Unit:** Home-based tour (individual or fully joint); work-based sub-tour  
**Segmentation:** Full segmentation by travel purpose for mandatory tours (work, university, school), full segmentation of non-mandatory tours by individual/joint setting, and segmenting out escorting tours and work-based sub-tours  
**Choice alternatives (190):** All possible combinations of 19 departure hours (from home or workplace) for outbound direction with 19 arrival hours (back home or to the workplace) for inbound direction; the modeled
departure and arrival hours range from 5 AM to 23 PM. Each time is rounded to the nearest hour. Any times before 5 are shifted to 5, and times after 23 are shifted to 23. Arrival time is always greater or equal to the departure hour for the same tour. Alternatives are considered unavailable if they span or overlap with one of the previously scheduled tours for the same person (or one of the members of the travel party for joint tours)

Main explanatory variables:

- Period-specific departure time constants:
  - Early departure (5 to 6)
  - AM peak left shoulder (7)
  - AM peak (8)
  - AM peak right shoulder (9)
  - Early midday departure (10 to 12)
  - Late midday departure (13 to 15)
  - PM peak (16 to 18)
  - Evening departure (19 to 21)
  - Late night departure (22 to 23)

- Period-specific arrival time constants:
  - Early arrival (5 to 6)
  - AM peak (7 to 9)
  - Early midday arrival (10 to 12)
  - Late midday arrival (13 to 15)
  - PM peak left shoulder (16)
  - PM peak (17)
  - PM peak right shoulder (18)
  - Evening arrival (19 to 21)
  - Late night arrival (22 to 23)

- Duration interval-specific constants (partially combined in a travel purpose specific way):
  - A constant for each duration from 0 to 11 hours
  - 12 to 13 hours
  - 14 to 18 hours

- Continuous shift variables for departure time and duration (applied after multiplication by the departure hour and duration consequently):
  - Highway travel time (MD, outbound direction)
  - Person type dummy
  - High/medium income dummies
  - Destination in CBD dummy
  - All adults in the household are full-time workers – dummy
  - 1st mandatory tour in a pattern with 2 mandatory tours for the same purpose (work, university, school)
  - 2nd mandatory tour of a pattern with 2 mandatory tours for the same purpose (work, university, school)
  - Higher priority tour of a pattern with 2 mandatory tours for different purposes (work/university, university/work, school/work)
  - Lower priority tour of a pattern with 2 mandatory tours for different purposes (work/university, university/work, school/work)
- Purpose-specific dummies for non-mandatory tours (shopping, other maintenance, discretionary, eating out)
- Dummy for adult traveling person and at least one child in the household (for individual non-mandatory tours)
- Position of the modeled individual non-mandatory tour in the chronological order if there are several individual non-mandatory tours made by the person for the same purpose:
  - 1st tour
  - Subsequent (2nd and later) tour
- Total number of tours made by the person:
  - Mandatory tours
  - Participation in joint non-mandatory tours
  - Individual non-mandatory tours (not including escorting and tours made for the same purpose as the modeled tour)
- Travel party size for joint tours:
  - Number of adults on tour
  - Number of children on tour
- Business-related purpose dummy for worked-based sub-tours
- Position of the modeled worked-based sub-tour in the chronological order if there are several worked-based sub-tours within the same work tour:
  - 1st sub-tour
  - Subsequent (2nd and later) sub-tour
- Full bi-directional mode choice log-sums for all combinations of outbound and inbound time-of-day periods:
  - NT/AM
  - NT/MD
  - NT/PM
  - NT/NT
  - AM/AM
  - AM/MD
  - AM/PM
  - AM/NT
  - MD/MD
  - MD/PM
  - MD/NT
  - PM/PM
  - PM/NT
- Dummy variables for “extreme” periods:
  - For mandatory activities:
    - High income / departure to work or school from 5 to 6
    - High income / arrival from work or school from 22 to 23
    - Destination in CBD / departure to work from 5 to 6
    - Destination in CBD / arrival from work from 22 to 23
    - Rural household / departure to work from 5 to 6
    - Rural household / arrival from work from 22 to 23
  - For non-mandatory activities:
    - Number of individual tours made / departure for escorting from 5 to 7
    - Number of individual tours made / arrival after escorting from 22 to 23
- Shopping tour (individual or joint) / departure from 5 to 8
- Shopping tour (individual or joint) / arrival from 22 to 23
- Maintenance tour (individual or joint) / departure from 5 to 7
- Joint eating-out tour / arrival from 22 to 23
- Preschool or school pre-driving-age child on individual or joint non-mandatory tour / arrival from 22 to 23
- University student on individual or joint non-mandatory tour / arrival from 22 to 23
- All adults on joint tour are full-time workers / arrival from 22 to 23
- All adults in the household are workers / at least one child in the household / departure for non-mandatory tour from 5 to 7

- Additional person, travel purpose, and pattern type dummy variable effects:
  - For mandatory tours:
    - Full-time worker / work duration less than 9 hours
    - Full-time worker / departure to work from 10 to 12
    - Part-time worker / arrival from work from 13 to 15
    - School driving-age child / school duration shorter than 7 hours
    - School pre-driving-age child / arrival from school at 16 PM
    - 1st work tour in a pattern with 2 work tours / duration shorter than 8 hours
    - 2nd work tour in a pattern with 2 work tours / duration shorter than 8 hours
    - Higher priority tour of a pattern with 2 mandatory tours for different purposes (work/university, university/work, school/work) / duration shorter than 8 hours
    - Lower priority tour of a pattern with 2 mandatory tours for different purposes (work/university, university/work, school/work) / duration shorter than 8 hours
  - For non-mandatory tours:
    - Dummy for adult traveling person and at least one child in the household / arrival from individual non-mandatory tour from 19 to 21
    - Dummy for non-working adult / departure for individual non-mandatory tour from 16 to 18
    - Dummy for discretionary tour (individual or joint) / duration shorter than 2 hours
    - Dummy for individual shopping tour / duration shorter than 2 hours
  - For worked-based sub-tours:
    - Dummy for business-related purpose / duration shorter than 2 hours
    - Dummy for eating-out purpose / duration 1 hour
    - Dummies for eating out purpose / departure at each of the hours 11, 12, 13
5.7. Entire Tour Mode Combination Choice Model

A detailed description of the tour mode choice model, the relevant statistical data and estimation results can be found in the corresponding technical report [21]. Below is the short description of the main structural features of the model.

**Unit:** Home-based tour (individual or fully joint); work-based sub-tour

**Segmentation:** Full segmentation by travel purpose for mandatory tours (work, university, school), full segmentation of non-mandatory tours by individual/joint setting, and segmenting out escorting tours and work-based sub-tours

**Choice alternatives (6):**
- SOV; not available for households without cars, preschool, and school pre-driving-age children; not available for joint and escorting tours
- HOV (if at least one trip is HOV)
- Transit with walk access (WT); not available if either origin or destination sub-zone has no transit access
- Transit with drive access including bi-modal combinations like P&R, K&R (DT); not available if the destination sub-zone has no transit access
- Non-motorized (NM); available for tours with distance shorter or equal to 3 miles only
- School bus (SB); available for school tours only

**Main explanatory variables:**
- Bi-directional (sum of inbound and outbound) travel time and cost origin-destination components for the corresponding time-of-day period combination:
  - In-vehicle time:
    - Highway time for SOV and HOV
    - In-vehicle transit time for WT and DT
    - Auto access time for DT
  - Walk time:
    - For WT depending on the origin and destination transit sub-zones (short/long walk)
    - For DT depending on the destination sub-zone (short/long walk)
    - For NM as a function of distance
  - Wait time for WT and DT including 1st and transfer wait
  - No of transfers for WT and DT
  - Highway toll for SOV and HOV scaled by the vehicle occupancy (average occupancy for individual HOV tours, travel party size for joint tours)
  - Operating cost for SOV and HOV as a function of distance and scaled by the vehicle occupancy (average occupancy for individual HOV tours, travel party size for joint tours)
  - Transit fare for WT and DT scaled by person-specific discounts
- Tour, person, household, and zonal characteristics:
  - Travel-purpose and mode specific constants for non-mandatory tours (individual and joint)
  - Person type dummies for individual tours
  - Travel party composition dummies for joint tours
  - Household income
  - Car ownership/sufficiency (in several cases in combination with the person type)
- Presence of a preschool or school pre-driving-age child in the household
- Parking cost as a function of zonal parking rate, tour duration, and person free-parking eligibility
- Work tour mode for work-based sub-tours
5.8. Stop-Frequency, Stop-Location, and Trip Mode Choice Model

In the current model system, stop-frequency, stop-location, and the following trip model choice model are applied for each motorized tour. **Figure 5.6** outlines the main structural features of this component of the model system.

![Stop-frequency, stop-location, and trip mode choice models](image)

A detailed description of the stop frequency, stop-location, and trip mode choice models as well as the relevant statistical data and estimation results can be found in the corresponding technical report [22]. Below is the short description of the main structural features for 2 sub-models (stop-frequency and stop-location). The trip mode choice model is currently reduced to the rule-based procedure for transit sub-modes based on the transit sub-mode chosen for the tour.

### 5.8.1. Stop-Frequency Choice Model

**Unit:** Motorized home-based tour (individual or fully joint); motorized work-based sub-tour  
**Segmentation:** Full segmentation by travel purpose for mandatory tours (work, university, school), full segmentation of non-mandatory tours by individual/joint setting, and segmenting out work-based sub-tours  

**Choice alternatives (4):**  
- No stops
• Outbound stop
• Inbound stop
• Both outbound and inbound stop

Main explanatory variables:
• Stop-location (density) log-sums; in several cases coefficients are partially segmented by income, person type (for individual tours), or travel party composition (for joint tours):
  o Outbound log-sum (for the 2nd and 4th alternatives)
  o Inbound log sum (for the 3rd and 4th alternatives)
• Tour characteristics; in several case coefficients are partially segmented by person type (for individual tours) or travel party composition (for joint tours):
  o Travel purpose-specific dummies (for non-mandatory tours and work-based sub-tours)
  o Duration
  o Early departure time dummy (from 5 to 6) for mandatory tours
  o Late departure time dummy (10 or later) for non-mandatory tours
  o Tour mode (SOV, HOV, transit)
  o Combinations of origin (residential) and destination area types:
    ▪ Urban origin / urban destination
    ▪ Urban origin / suburban destination
    ▪ Urban origin / rural destination
    ▪ Suburban origin / urban destination
    ▪ Suburban origin / suburban destination
    ▪ Suburban origin / rural destination
    ▪ Rural origin / urban destination
    ▪ Rural origin / suburban destination
    ▪ Rural origin / rural destination
  o Number of worked-based sub-tours for the work tour (for work-based sub-tours)
• Person, travel party, and individual pattern characteristics:
  o Person type dummies for individual tours
  o Travel party composition dummies for joint tours
  o Person daily pattern (mandatory/non-mandatory) for non-mandatory tours
  o Total number of individual and joint participations in non-mandatory tours
• Household characteristics:
  o Household income
  o Car ownership/sufficiency (in several cases in combination with the person type)
  o School tour made by school child in the household for modeled adult persons
  o Total number of individual and joint non-mandatory tours made by the household
5.8.2. Stop-Location Choice Model

**Unit:** Half-tour (outbound or inbound) of either motorized home-based tour (individual or fully joint) or motorized work-based sub-tour

**Segmentation:** Full segmentation by travel purpose and direction for mandatory tours, individual/joint setting for non-mandatory tours, and segmenting out work-based sub-tours

**Choice alternatives (5,415):** 1,805 TAZs with subdivision by 3 transit accessibility zones; sub-zones with zero size variable are not available; sub-zones not accessible by the main transit sub-mode are not available for transit tours

**Main explanatory variables:**
- Logged sub-zonal size (stop-attraction) variable, calculated as a linear combination of the relevant land-use variables for each travel purpose; stop attractions for mandatory purposes (work, university, school) are purpose and direction specific; stop attractions for non-mandatory tours and work-based sub-tours are fully segmented by purpose only
- Deviation from the shortest path between the half-tour origin and destination:
  - Absolute deviation calculated as a sum of distances between the origin and stop and between the stop and destination minus the distance between origin and destination
  - Relative deviation calculated as a ratio of the sum of distances between the origin and stop and between the stop and destination to the distance between origin and destination
- Statutory border crossing:
  - intra-county dummy for non-mandatory tours (origin, destination, and stop belong to the same county)
  - intra-district dummy for school tours (origin, destination, and stop belong to the same school district)
- Transit access dummy for a combination of short walk sub-zones for the origin, destination, and stop for transit tours
6. Reference


