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DEVELOPMENT OF CONTINUOUS TIME, TEMPORALLY CONSTRAINED AND BEHAVIORALLY CONSISTENT TOUR PATTERN GENERATION SYSTEM FOR MODELING THE IMPACTS OF AUTONOMOUS VEHICLE FUTURE

Final Report

by

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DISCLAIMER

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EXCUTIVE SUMMARY

The primary objective of this research is to operationalize a new tour-based travel behavior modeling framework that addresses three limitations of existing frameworks. First, it represents time as a continuous entity. Second, it captures the interrelationship between stops and tours across the day. Third, it accommodates the temporal constraints within which an individual generates trips and activities. More specifically the report documents models that help implement the framework. A key contribution of the research is in the use of Multiple Discrete-Continuous Extreme Value (MDCEV) modelling approach formulated by Bhat [1]. The report documents the models developed.

Chapter 1. Introduction

1.1 Problem Statement

Over the last a few years, the Autonomous Vehicle (AV) technology and solutions have made significant progress in bringing the futuristic fantasy to nearby reality. As many major players announced that the AVs will be available on the market within next a few years, there are still a lot of uncertainties associated with AVs remaining for exploration. Optimists of AVs claim that AVs can be beneficial in various fields. On mobility aspect, AVs hold the promise to improve mobility for many groups such as the non-drivers, the elderly population, and people with travel-restrictive medical condition [2] [2]. With AVs, these groups of people can be well served either by shared autonomous vehicles (SAV) or privately-owned AVs. In addition to the underserved populations, the mobility of other groups of people could also be increased due to the ease of travel and reduced travel cost by AV usage [3]. For the safety aspect, AVs are expected to improve traffic safety since they require much less reaction time when encountered with accident compared with human drivers [4], AVs are expected to significantly reduce crashes by avoiding human errors [5] [6] [7]. For congestion and traffic operations, AVs are expected to effectively reduce road congestion due to their traffic-flow-smoothing capabilities, vehicle to vehicle communication technology (V2V), and smarter routing strategies [8] [9]. For land use, AVs are expected to free up a large scale of urban areas where are currently been used as parking space. AVs are be able to relocate themselves either to find a free parking space outside the urban core or proceed to serve others if offered as a shared mode [10]. However, many skeptics and opponents of AVs expressed concerns to the claimed benefits. AVs can potentially lead to a dramatic increase in overall vehicle miles traveled (VMT) either due to the new demand generated by the underserved population or by the existing drivers. With AVs, driving is no longer a tedious task, but instead it is a journey where people can perform various types of activities such as working, entertainment and sleeping [11]. Nevertheless, although AVs are expected to park themselves far away from dense urban area to free up urban space, it may also result in a significant increase in zero-occupancy vehicle miles traveled. With that, any congestion and mobility benefits may be substantially or entirely offset [6]. Moreover, it was also found that most of the benefits of AVs are claimed under the assumption that AVs are operated as a shared mode instead of privately owned. Even through there are many uncertainties associated with AV implementation, their impact on travel behavior are undeniable.

Analytical tools or approaches are in need to evaluate the impacts of AVs under different policies and service types.

1.2 Objectives

The primary objective of this research is to enhance an existing Activity-Based Travel demand modeling system (ABM) named as San Francisco Chained Activity Model Process (SF-CHAMP) by applying Multiple Discrete-Continuous Extreme Value (MDCEV) modelling approach formulated by Bhat [12]. The enhanced framework is behaviorally more consistent with travel behavior compared to existing framework. First, it represents time as a continuous entity. Second, it captures the interrelationship between stops and tours across the day. Third, it accommodates the temporal constraints within which an individual generates trips and activities.

Results from the enhanced framework and original SF-CHAMP will be compared to indicate the feasibility of the enhanced framework. For evaluating the impact of AVs, a scenario based study will be conducted to quantity the implications of AVs under different service offerings.

1.3 Expected Contributions

The research will help enhance the APG stage of existing TABM. A memo describing the approach used to integrate the enhancements into an existing TABM will be prepared. The feasibility and applicability of the enhanced TABM will be demonstrated by comparing the travel outcomes and varies computational measures from the enhanced TABM against that from the existing TABM. The enhanced TABM will be applied to study the impacts of different AV service offerings. The findings from the research will help both public and private industry chart the way for developing solutions and policies that meet mobility, livability, and sustainability needs of urban cities and regions around the US.

1.4 Report Overview

The rest of the paper is structured as follows. Chapter 2 provides a brief discussion on literature review of different methods for AV analysis. It is followed by a short description of tour-based activity-based travel demand model (TABM). In Chapter 3, a brief introduction of the formulation of MDCEV model is provided. In addition, the section also demonstrates the existing model framework and the enhanced model framework. Chapter 4 presents an overview of model estimation results along with some observations, and discussion of findings. Finally, concluding thoughts along with limitations and future extensions are presented in Section 5.

Chapter 2. Literature Review

2.1 Introduction

In this section, a brief overview of existing methods for studying AV implication is presented. It is followed by a short description of an existing TABM framework and its limitations.

2.2 Impact of AVs

Several methods have been applied by researchers to study the potential implications of AV technologies. In general, the studies can be classified into four categories including: 1) speculative studies [12] [13]; 2) analytical and simulation based studies [2] [14] [15] [16] [17]; 3) survey based studies [18] as well as 4) virtual reality or simulator based studies [19] [20].

Speculative studies tend to convey possibilities of AVs implications based on information and data from existing modes. For example, studies have found that the emergence of shared ride, such as Uber and Lyft, changes car ownership patterns. They speculate such change will also be observed caused by implementation of SAVs [62]. Analytical and simulation based studies use the pre-defined assumptions to simulate the individual's travel behavior and network operations under the different AV implementation scenarios [2] [14] [15] [16] [17]. Meyer et al., [17] simulated impact of AVs on accessibility of Swiss municipalities use Swiss national transport model. They assumed 80% to 270% increase in highway capacity and 40% increase in urban road capacity due to AV implementation. They also assumed that new vehicle demands are generated because of new users substitute other modes to AVs. Based on their simulation result, they pointed that overall AVs can provide increase in accessibilities. However, when demand increased drastically, the accessibility decreases. Survey studies design questionnaires for collecting data from individuals to analyze different aspect of AVs. The commonly asked questions include willing to pay, mode choice, and ownership etc., In order to study the adoption of AVs with distinction between shared and owned vehicles, Krueger et al., [18]distributed an online state preference mode choice survey to 435 residents in Australia, they found that young individuals and individuals with multimodal travel patterns may be more likely to adopt SAVs. Virtual reality or simulator based approach overcomes issue of lack of realism of the stated preference survey approach by developing highly realistic environment of the AV future. Farooq et al. [20] developed a virtual immersive reality environment platform for conducting a range of stated preference experiments in a highly realistic, immersive, interactive environment. They used this platform to explore pedestrian acceptance of autonomous vehicles and associate infrastructure changes in urban setting. By comparing the result with the result from a text-only and a visual animation survey, they found that the experiment tools have significant impact on the result. The virtual immersive reality environment has a positive impact on the respondent's perceptions of autonomous vehicles.

2.3 Tour Based Activity Based Model

The proposed method of this study contributes to the analytical and simulation approach by enhancing an existing TABM system to allow accurate modeling of individual's time use and travel behavior under different AV service offerings. Activity-based model (ABM) systems have been gaining significant research attention in recent years due to their behaviorally accurate representation of individual activity-travel pattern under various policies and planning applications. Unlike traditional trip-based travel demand model systems that predict aggregate-level (i.e., TAZ level) travel demand for long-term socio-economic scenarios, the ABM systems focus on modeling various aspects of disaggregate-level (i.e., individual-level, household-level) activity-travel pattern impacted by short-term demand management policies such as congestion pricing and singe occupant vehicle regulation [21].

TABM systems use tour as analysis unit. The systems subdivide individual's daily activity-travel schedule into a set of tours. TABM represents the most advanced state of the practice of ABMs. These systems have been widely adopted by the transportation agencies and authorities (i.e., Sacramento Area Council of Governments (SACOG), Denver Regional COG (DRCOG), Metropolitan Transportation Commission at San Francisco, CA (MTC)) [22]. A tour is defined as a sequence of trips starting and ending at home or work anchor location. If a tour is anchored at home it is defined as a home-based tour, while if it is anchored at work location it is defined as a work-based (WB) subtour. Individual activity-travel pattern can be characterized as a set of tours with each tour consists of a primary destination and a series of intermediate stops either before or after the primary destination. In the state-of-the-art tour-based modeling approaches, daily activity-travel patterns of the decision makers are formed in two stages, namely, the activity pattern generation (APG) and the activity scheduling (AS). The APG is the identification of characteristics of all tours including tour purpose, number of stops within a tour, purpose, mode and destination for each stop and time allocated to all tours and stops among other decisions. The AS stage models the timing and placement of tours stops within a day. The advantage of TABM systems compared to traditional trip based modeling systems is that they treat time as an all-encompassing continuous entity while the latter treat time as a simply “cost” for making trips [23]. However, due to the ease of applicability, almost all of the TABM systems in practice today represent time in discrete units [24]. Second, most tour-based model systems do not explicitly acknowledge the temporal constraints when modeling tours, or when modeling stops within a tour. Temporal constraints are often accommodated afterwards using heuristics and logical checks at the activity scheduling stage. To this end, the proposed method of this study contributes to the enhancement of the APG stage of the existing TABM framework by addressing the above mentioned two limitations.

Chapter 3. Methodology

3.1 Introduction

In this section, the formulation of MDCEV model is first introduced to show the capability of improving existing TABM framework. After that, the model framework of DaySim is introduced including an explanation of how it represents time and imposes temporal constraints. An enhanced modeling framework is then provided to demonstrate the proposed modeling system. Additionally, a description of MDCEV model is also presented in this section.

3.2 MDCEV

MDCEV is a utility theory-based model for discrete/continuous choice that derived and formulated by Bhat [23]. The major difference of the MDCEV model framework in activity participation, in contrast to the standard discrete choice model, is that it assumes that the alternatives imperfectly substitutable for each other. This assumption leads a multiple discreteness model which allows to the simultaneously choose of multiple activities and allocate time to each chosen activity given a resource constraint. The activity generation stage of SF-CHAMP will be replaced by MDCEVs. Instead of sequentially modeling number of tours a person undertakes and the time allocated to them, the MDCEV directly determines a series of home based tours that an individual pursuits as well as the time allocation to each tour. Moreover, it can also determines time allocation for in-home activities (i.e., time allocation at home before the first trip of the before, time allocation at home after returned from the last trip of the day, time allocation at home between out-of-home activities). After generating tour pattern for each individual, the intermediate stop participation and time allocation within each tour are also modeled by MDCEV.

Following Bhat, The MDCEV model assumes a translated non-linear additive specification for the utility function. Assume there are K different home based tour purposes that an individual can choose to allocate time to. Let t_j be the time allocated to tour purpose j $(j = 1,2,3, \dots, K)$. The utility accrued to the individual is specified as the sum of the utilities obtained from investing time in each tour purpose, which can be expressed as equation (1):

$$U = \sum_{j=1}^{K} \psi(x_j)(t_j + \gamma_j)^{\alpha_j} \quad ; \quad (0 < \alpha_j \leq 1) \tag{1}$$

$$\psi(x_j, \varepsilon_j) = \exp(\beta' x_j + \varepsilon_j) \tag{2}$$

Where $\psi(x_j)$ is the baseline utility for time allocated to activity purpose j; To ensure that utility is greater than 0, ψ is defined as an exponential function of observed characteristics x_j and unobserved characteristics ε_j associated with activity purpose j, where ε_j is assumed to be independent and identically type I extreme value distributed across tour purposes and individuals. The utility function belongs to the family of translated utility functions, where γ_j determines the translation and α_j influences the rate of diminishing in marginal utility of allocating time in activity purpose j. Based on utility maximization theory, individual is seeking to maximize the sum of the utilities subject to the time budget constraint T:

Maximize: $U = \sum_{j=1}^{K}[\exp(\beta' x_j + \varepsilon_j)\left(t_j + \gamma_j\right)^{\alpha_j}]\ ;\ (0 < \alpha_j \leq 1)$ (3)

Subject to: $\sum_{j=1}^{K} t_j = T$ (4)

The optimal time allocations can be found by applying the Lagrangian function. The same model framework will also be applied for intermediate stop participation and time allocation within a tour where the time budget is the allocated time for that tour. In this framework, time is treated as a continuous entity thus allocations of time to tours and stops are in continuous time units. The temporal constraints are incorporated in the model framework. First, total time allocation across all tours and in-home activities is constraint to the total time available in a day (i.e., 1440 minutes). Second, total time allocation across all stops within a tour is equal to the time allocation for the said tour [23].

3.3 Enhanced Model Framework

The APG stage of SF-CHAMP is achieved by DaySim which is an activity-based travel simulator developed by Bowman and Ben-Akiva [25]. The APG stage of DaySim first determines the main pattern of travel for each individual. A multinomial logistic regression (MNL) is applied to jointly estimate the participation of home-based (HB) tour a person undertakes during a day for seven purposes, and the occurrence of additional stops during the day for the same seven purposes. After this, another MNL is applied to determine the exact number of tours that an individual pursuits for a given purpose. For each tour, the exact number of intermediate stops and their purposes are estimated through a MNL. The outcomes of the model is strongly conditional on main pattern of travel predicted at the first step. For the last modeled tour, the model is constrained to accomplish all intermediate stops purposes predicted at the first step. The timing of tour and stop are estimated through time-of-day models which determines tour primary destination arrival and departure time, and intermediate stop arrival or departure time. The time-of-day models are also a set of MNLs which determine the combination of arrival and departure time by dividing a day into 48 time slots with 30-minute interval. It can be seen that the existing APG stage is based on a large number of independent MNLs and discrete time unit. Table 3.1 shows the component models of APG stage of DaySim.

Table 3.1 Component Models of APG stage of DaySim Standard [26]

Model Name	Level	What is predicted
Day Activity Pattern	Person-day	0 or 1+ tours for 7 activity purposes. 0 or 1+ stops for 7 activity purposes
Exact Number of Tours	Person-day	For purposes with 1+ tours: 1, 2 or 3 tours.
Tour Primary Destination	(Sub)Tour	Primary destination zone and parcel (models are purpose-specific)
Tour Main Mode	(Sub)Tour	Main tour mode (models are purpose-specific)
Tour Time of Day	(Sub)Tour	The time period arriving and the time period leaving primary destination (models are purpose-specific)
Intermediate Stop Generation	Half Tour	Number and activity purpose of any intermediate stops made on the half tour, conditional on day pattern
Intermediate Stop Location	Trip	Destination zone and parcel of each intermediate stop, conditional on tour origin, destination, and location of any previous stops
Trip Mode	Trip	Trip mode, conditional on main tour mode
Trip Departure Time	Trip	Departure time within 30 min. periods, conditional on time windows remaining from previous choices

The proposed study will focus on the improvement regarding to four dimensions of the existing APG stage, namely, 1) the choice of participation in different types of home based tours, 2) time allocation to each tour, 3) the choice of participation in different intermediate stops within each tour, and 4) time allocation to each stop. Other dimensions of individuals' APG such as destination choice of stops, mode choice of trips will be modeled using existing approaches. The component models of the enhanced model framework is shown in table 3.2. First, a binary logit (BL) model is estimated to identify if a person pursues any tour during day. Then, two types of travelers are distinguished by a BL model namely, unique traveler and non-unique traveler. Unique traveler is defined as the individuals who make at most 1 tour with the same purpose, while non-unique traveler is defined as the individuals who make more than 1 tours with the same purpose. The reason of segmenting unique and non-unique traveler is because of that their time use pattern is quite different based on descriptive analysis. Two MDCEV models are trained for estimating activity-travel pattern for unique and non-unique travelers. The model directly predicts the purpose, number, and duration of all tours an individual undertake during a day. Meanwhile, three homestay durations are also included as alternatives in the model's choice set including initial homestay duration, final homestay duration, and intermediate homestay duration. The initial homestay duration is defined as the time spent at home before the start of the first tour. The final homestay duration is defined as the time spent at home after the end of the last tour of the day. The intermediate homestay duration is defined as the time spent at home between two consecutive tours. The model is forced to predict non-zero duration for initial homestay, final homestay, and primary tour, while the predicted duration of intermediate homestay and non-primary tours can be 0. Additionally, for unique traveler, there is only one alternative for each tour purpose, but for non-unique traveler, there can be more than one alternatives with the same tour purpose which presents the multiple tours of the same purpose the person pursued (i.e., work tour 1, work tour 2). After determining the tour pattern for each individual, a BL is estimated to predict if a HB work tour contains any WB subtours. Then a WB subtour pattern model is trained by applying a similar formulation of the activity pattern model. Once all the tours are being predicted, seven intermediate stop generation models are trained for each tour purpose to simultaneously predict purpose, number, and duration of intermediate stops within a tour. The stop purpose enumeration of the seven models are different. For example, it is observed that a work tour rarely has a school stop, therefore, school stop purpose is not being included in the choice set of the intermediate stop generation model of work tour. After all tours and intermediate stops being generated, Several sequencing models will be built to determine the sequential order of HB tours, WB subtours, and intermediate stops. Two split models will be introduced. One is to split total intermediate homestay time to each tour and the other is to split the stop duration time into travel time and activity-dwell time. As can be seen, with the enhanced framework, time is always being represented as a continuous entity, and also no additional heuristic checks are needed to impose the temporal constraint.

Table 3.2 Component Models of APG stage of Enhanced Model Framework

Model Name	**Level**	**What is predicted**
Zero Tour Person	Person	0 tour person, 1+ tour person
Traveler Type	Person	Unique travelers, non-unique travelers
Day Activity Pattern – Unique Travelers	Person-day	Purpose, number, and duration of tours for 7 purposes and homestay duration
Day Activity Pattern – Non-unique Travelers	Person-day	Purpose, number, and duration of tours for 7 purposes and homestay duration
Zero Work-Based Subtour	Tour	0 WB subtour, 1+ WB subtour
Work-Based Subtour Pattern	Tour	Purpose and duration of primary activity; purpose, number, and duration of intermediate stops; duration of intermediate work stay
Intermediate Stop Generation	Tour	Purpose, number and duration of intermediate stops for each HB tour; determine duration of primary activity
Tour Sequencing	Tour	Sequence of tours during the day
Intermediate Homestay Splitting	Person-day	Homestay duration for each tour
Work-Based Sub-Tour Sequencing	Tour	Sequence of work-based subtours within each parent home-based tour
Stop Placement	Tour	Which half-tour the stop belongs to
Stop Sequencing	Half Tour	Sequence of intermediate stops of each half-tour
Epoch Duration Splitting	Stop	Travel time and activity dwell time for each stop

Chapter 4. Observations from Model Estimation

4.1 Zero Tour Person

Zero Tour Person model was estimated at the person level and a binary logistic model was used to estimate if a person makes any tour during a day. There were 2 alternatives: 0 – zero-tour person; 1 – non-zero tour person. The mean log-likelihood value of this estimation was -12932. The significant variables were selected based on P-value of less than or equal to 0.1. From the estimation results, it was evident that the explanatory variables used in this model estimation are not sufficient for distinguishing the zero-tour and non-zero-tour persons. Some important observations from this model estimation results are as following:

- Retired persons, non-workers are less likely to make any tour during a day.
- Persons in household with 2 vehicles are more likely to make tours.
- If a person is the only adult in the household, s/he is more likely to make tours.
- Number of children in household has positive coefficient for making tours.
- Driver and part-time students are more likely to make tours.

4.2 Traveler Type

Travel Type model is also a binary logistic model that was used to estimate if a traveler (who makes at least one tour) is a unique traveler or non-unique traveler. A unique traveler is the traveler who makes at most 1 tour for each tour purpose. A non-unique traveler is the person who makes two or more tours for the same tour purpose. The model is estimated and operated at person level. There were 2 alternatives: 0 – non-unique traveler; 1 – unique traveler. With a mean likelihood value of -5217.8, P-value of less than or equal to 0.1 was used to select the significant variables. Using the estimated parameters, it was found that the predicted values are very close to the true values. In other words, the performance of this model was satisfactory. Some critical observation from estimated parameters are listed as following:

- Retired persons, non-workers, drivers are less likely to be unique traveler.
- Young adults (age 16 to 35) are more likely to be unique travelers.
- Part-time students and persons with transit pass are more likely to be unique travelers.
- Persons from vehicle deficient household are less likely to be unique travelers.
- Workers who work from home are less likely to be unique travelers.

4.3 Day Pattern for Unique Travelers

An MDCEV model was used to estimate the day pattern for unique travelers. The model was used to determine the purpose, number and duration of tours, and home stay duration (initial, intermediate and final) for each unique traveler. The model was estimated at the person-day level using the sample information of unique travelers. There were 10 alternatives in this model including 2 outside, 1 composite inside and 7 inside goods. The mean log-likelihood value for this model estimation was -20.6472. Utility specification configuration of 4 was used with Alpha value constraining between 0 to 1. The significant parameters were selected based on P-value of less than or equal to 0.2. Time spent at work, school and meal can be explained by almost all the explanatory variables. Some other findings about the influence of explanatory variables in determining the day pattern of unique travelers are as following:

- Persons with age between 16-25 years are likely to spend time at school and for social activities.
- People with age of at least 65 years spend time in personal business.
- Males are more likely to spend time for meal and at work.
- Persons with transit pass spend time at work and for meal and shop.
- University students are more likely to spend time for meal.
- Retired persons and non-workers spend time for shop, meal, personal business and social activities. Non-workers are also likely to spend time for escorting.
- People who work from home are likely to spend time on intermediate home stay and for meal, work and escorting.
- Persons with household income less than $25,000 spend time at school. People with household income less than $50,000 also spend time at school including shopping.
- The person who is the only adult in a household is more likely to spend time at work and shopping.
- The person who is the only worker in a household spend time at school and personal business.

4.4 Day Pattern for Non-unique Travelers

The day pattern generation for non-unique travelers is also based on an MDCEV model that serves the same purpose as the model for unique travelers and was estimated at the person-day level using the sample information of non-unique travelers. There were 14 alternatives in this model including 2 outside, 1 composite inside and 11 inside goods in this MDCEV model. The mean log likelihood value of this estimation was -34.3177. The model configurations and parameter selection criteria were the same as those for unique travelers. Some important observations from the estimation results can be summarized in the following list:

- Persons with age between 16-25 years are likely to spend time at work and for personal business.
- People with age of at least 65 years spend more time in shopping.
- Males are more likely to spend more time at work and for meal.
- Persons with transit pass spend time for shopping.
- Retired persons usually spend time for shop and personal business.
- People who work from home are less likely to make any tours or spend time on any purposes.
- The person who is the only worker in a household spend time for escorting and tend to have longer intermediate stay at home.
- Students who are more than 16 years old usually spend time at school and social activities.
- Persons with household income less than $25,000 are more likely to spend time for shopping and escorting and in intermediate stay at home. People with household income less than $50,000 spend time at work.
- The persons who have workday flexibility tend to spend more time at work.
- The persons who are the only adult in the household are more likely to spend time for meal and personal business.

4.5 Zero Work-based Subtour

Zero Work-based Subtour model was formulated to estimate if a home-based work tour has subtours. The model was a binary logistic model estimated at the tour level with two alternatives: 0 – non-zero subtours; 1 – zero subtours. In this model estimation, the mean log likelihood value was -2945.5 and P-value of less than or equal to 0.15 was used to select significant explanatory variables. The performance of this model was satisfactory, and the predictions were close to true observations. Additional observations about the role of variables determining if a home-based work tour has subtour are given as follows:

- Retired person, other non-worker, and part-time student are more likely to have zero work based subtour
- Middle aged person (36 to 45 years old), driver, and transit pass holders are less likely to have zero work based subtours
- Number of persons in household have positive effect on having zero work based subtour
- Parent home-based work tour duration has negative effect on having zero work based subtour. The longer the home-based work tour, the more likely it has subtours.

4.6 Work-based Subtour Pattern

Work-based Subtour Pattern model was used to determine the purpose, and duration of primary activity and intermediate stops in a work tour. This is an MDCEV model estimated at the home-based work tour level with 9 alternatives in this model including 2 outside, 1 composite inside and 6 inside goods. The model configuration was same as the previous MDCEV models. The model was estimated using a relatively smaller dataset and the mean log likelihood value was -17.6121. All explanatory variables can explain time spent at work, school and meal. Some other observations based on the estimated parameters are given below:

- Males are more likely to spend time for meal and takes longer in their way back to the workplace.
- Persons with age between 16-25 years are likely to spend time at work.
- People with age of at least 65 years spend time in personal business.
- Persons with workday flexibility tend to spend more time in the final work stay.
- People who are employed and have a driver's license and who have transit pass are less likely to spend time outside their workplace for any purpose.
- Persons who have more than 1 jobs are more likely to make subtours for work, social and escorting.
- People from household with more than 2 operational vehicles do not make any work-based subtour.
- The person who is the only worker in a household tend to spend more time on final work stay.

- If the tour mode is SOV, the persons tend to make work-based subtour for work and shopping.
- If the tour mode is carpool, the persons are more likely to make subtour for meal.
- If the tour mode is walk and bike, the persons usually make work-based shopping subtours.
- If the tour mode is transit, people usually takes longer to return to their workplace.
- Unique travelers are more likely to spend time on escorting of their work-based tours.

4.7 Intermediate Stop Generation

To determine the number, duration and purpose of stops for all home-based tours, different MDCEV models were estimated for each tour purpose. Each model has a different number of alternatives. However, the utility specification configuration and Alpha constraints were the same for all models. The following sections illustrate some major findings from each individual model estimation.

4.7.1 Intermediate Stop Generation for Work

- Males are more likely to stop for work.
- Persons with age between 25-64 years are likely to stop for shop and escorting.
- People with age of at least 65 years are less likely to make any stop in their home-based tours.
- Persons who have a driver 's license are more likely to stop for shop and social activities.
- People who have more than 1 jobs normally make stop for work and meal.
- Persons with transit pass do not stop for any purposes in their home-based tours.
- Persons from the household with more than 2 operational vehicles are more likely to stop for work, shop and personal business.
- The person who is the only adult in a household normally stop for shopping.
- Persons who are not students are likely to stop for work and escorting.
- Retired persons stop for work, social activities and shopping.
- Part-time students generally stop for work, shopping and escorting.
- Persons with household income less than $25,000 usually makes work stops. People with household income less than $50,000 are likely to stop for escorting.
- People who work from home are likely to stop for work related purposes, meal and escorting.

- If the tour duration is between 3 to 6 hours, the persons are more likely to stop for work, shopping, personal business and escorting.
- If the persons make more than 2 trips in that tour, they normally do not stop for any purposes.
- If there is more than one vehicle per adult in the household, they usually stop for personal business.

4.7.2 Intermediate Stop Generation for School

- Persons with age between 25-64 years are less likely to stop for any purposes.
- Persons who have a driver 's license normally do not stop in their home-based school tours.
- People who have more than 1 jobs are likely to stop for personal business.
- Persons from the household with more than 2 operational vehicles are more likely to stop for a meal in their home-based school tours.
- The person who is the only adult in a household normally stop for school, shopping and social activities.
- Retired persons usually stop for social and other activities.
- Part-time students generally do not stop for any purposes.
- People with household income less than $50,000 are likely to stop for escorting.
- People who work from home are likely to stop for work related purposes, meal and escorting.
- If the tour duration is between 3 to 6 hours, the persons are more likely to stop for shopping.
- People who get transit subsidy do not normally stop for any purposes.
- If the persons make more than 2 trips in that tour, they normally spend more time in their primary activity.
- If there is more than one vehicle per adult in the household, they usually stop for shopping and personal business.

4.7.3 Intermediate Stop Generation for Meal

- Persons with age between 16-25 years do not stop for any purposes.
- People with age of at least 65 years are likely to make stop for shopping and personal business.

- Persons with transit pass are less likely to stop for any purposes in their home-based meal tours.
- Persons from the household with more than 2 operational vehicles are more likely to stop for personal business, social and other activities in their home-based meal tours.
- The person who is the only worker in a household normally do not stop for any purpose.
- Part-time students also generally do not stop in their home-based meal tours.
- People who work from home are likely to stop for personal business.
- If the tour duration is between 3 to 6 hours, the persons are more likely to social and other activities and spend more time on their primary activities.
- If the persons make more than 2 trips in that tour, they normally spend more time on their primary activities and takes more time to return home.
- People who have flexibility in their workday schedule do not make any stops.

4.7.4 Intermediate Stop Generation for Shopping

- Males are less likely to make any stop in their home-based shopping tours.
- Persons with age between 25-64 years are likely to stop for personal business.
- Persons with age at least 65 years usually stop for shopping and personal business.
- Persons who have a driver's license normally do not stop in their home-based shopping tours.
- People who have more than 1 jobs are likely to stop for personal business.
- Persons having transit pass generally do not stop for any purposes.
- Persons from the household with more than 2 operational vehicles are more likely to stop for a meal in their home-based shopping tours.
- The person who is the only adult in a household normally stop for personal business and take more time to return home.
- Non-students are likely to stop for social and other activities during home-based shopping tours.
- Retired persons usually stop for personal business.
- People with household income less than $25,000 normally do not make stop. People with household income less than $50,000 are likely to stop for personal business and takes longer to return home.

- If the tour duration is between 3 to 6 hours, the persons are more likely to stop for personal business.
- People who get transit subsidy stop for shopping.
- If the persons make more than 2 trips in that tour, they normally spend more time in their primary activity and takes more time to return home. If there is more than one vehicle per adult in the household, they usually stop for personal business and social activities.

4.7.5 Intermediate Stop Generation for Social and Recreational Activities

- Males are less likely to make any stop in social and other tours.
- Persons with age between 16-25 years spend more time on primary activity on their home-based social and other tours.
- Persons with age at least 65 years usually stop for personal business and they also spend more time on primary activity.
- People who have more than 1 jobs are also likely to stop for any purposes.
- Persons from the household with more than 2 operational vehicles are more likely to stop for social activities and spend more time on primary activity in their home-based social and other tours.
- The person who is the only adult in the household usually stop for personal business.
- Retired persons are likely to stop for social activities.
- People who work from home normally stop for personal business.
- People with household income less than $25,000 are likely to make stop for social and other activities.
- Part-time students and students with age below 16 years tend to spend time on primary activity.

4.7.6 Intermediate Stop Generation for Personal Business

- Males are less likely to make any stop in personal business tours.
- Persons with age between 16-25 years spend more time on primary activity on their home-based personal business tours.
- Persons with age at least 65 years usually stop for social and activities and they also spend more time on primary activity.
- People who have workday flexibility tend to spend more time on the primary activity and stop for personal business.

- People who have more than 1 jobs are also likely to stop for personal business.
- People who get transit subsidy do not stop for any purposes in personal business tours.
- Persons from the household with more than 2 operational vehicles are more likely to stop for social activities and spend more time on primary activity in their home-based personal business tours.
- The person who is the only worker in the household normally spend more time in the primary activity. The person who is the only adult in the household do not make any stops.
- Retired persons usually stop for personal business.
- People with household income less than $25,000 normally do not make stop. People with household income less than $50,000 are likely to stop for personal business.
- Part-time students are more likely to spend more time on primary activity.
- Students with age below 16 years tend to spend time on primary activity and make a stop for social activity in the home-based personal business tours.
- Persons having transit pass generally do not stop for any purposes. If the tour duration is between 3 to 6 hours, people make stop for both personal business and social activities and spend more time on primary activity.

4.7.7 Intermediate Stop Generation for Escort

- Males are less likely to stop for any purposes in their home-based escort tours.
- People with age of at least 65 years are more likely to make stop for shopping and escorting.
- People who have more than 1 jobs normally do not stop during their escort tours.
- Persons from the household with more than 2 operational vehicles are more likely to stop for escorting.
- The person who is the only adult in a household normally stop for social and other activities.
- Persons who are not students are less likely to stop for any purposes.
- Retired persons usually stop for personal business.
- Part-time students generally do not stop during their escort tours.
- People with household income less than $50,000 are likely to stop shopping.
- People who work from home are likely to stop for personal business and they tend to spend more time in primary activity.

- If the tour duration is between 3 to 6 hours, the persons are more likely to stop for meals, personal business, social activities and escorting.
- If there is more than one vehicle per adult in the household, it usually takes longer to finish their primary activity.

Chapter 5. Summary and Conclusions

5.1 Summary and Conclusions

The primary objective of this research is to enhance an existing Activity-Based Travel demand modeling system (ABM) named as San Francisco Chained Activity Model Process (SF-CHAMP) by applying Multiple Discrete-Continuous Extreme Value (MDCEV) modelling approach formulated by Bhat [12]. The enhanced framework is behaviorally more consistent with travel behavior compared to existing framework. The enhanced model framework in chapter 3 demonstrated its superiorities compared to the existing model framework. First, it represents time as a continuous entity. Second, it captures the interrelationship between stops and tours across the day. Third, it accommodates the temporal constraints within which an individual generates trips and activities. 13 models have been estimated for generating day activity tour pattern, WB subtour pattern, and also intermediate stops. It was found that social-demographic characteristics are highly related with individual's activity-travel pattern.

5.2 Directions for Future Research

The research is still in progressing. There are several tasks remaining for future research. First, there are several models in the proposed framework have not been yet being estimated. Second, current model formulation only use sociodemographic related information as exogenous variables. Accessibility measurements and land use, which are essential for APG modeling system, are not yet been included due to limited data access. Third, results from the enhanced framework and original framework need to be compared to evaluate the feasibility of the enhanced framework. Finally, the enhanced model framework is expected to be used for evaluating the impact of AVs under different service offerings.

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Appendices

A) Zero Tour Person

Table A3 – Details of alternatives

Alternatives	Description
nonzero_tour == 0	The person did not make any tour
nonzero_tour == 1	The person made at least one tour

Table A4 - Details of independent variables

Variables	Description
Intercept	Intercept
retired	1 if retired, 0 otherwise
nonwrk	1 if non-worker other than retired, 0 otherwise
veh2	1 if household owns 2 vehicles, 0 otherwise
num_kids	number of kids in household
onlyadlt	1 if the person is the only adult in household, 0 otherwise
driver	1 if driver, 0 otherwise
std_part	1 if part-time student, 0 otherwise

Table A3 - Estimation of parameters

Parameters	Estimates	Std.Err.	z	P>|z|	[0.025	0975]
Intercept	0.5884	0.0502	11.7198	0	0.49	0.6868
retired	-0.787	0.0417	-18.8518	0	-0.8688	-0.7052
nonwrk	-0.6098	0.0467	-13.07	0	-0.7012	-0.5183
veh2	0.1655	0.0316	5.2343	0	0.1035	0.2274
num_kids	0.5303	0.0622	8.5283	0	0.4084	0.6522
onlyadlt	0.3066	0.0587	5.2197	0	0.1915	0.4218
driver	0.7569	0.0495	15.303	0	0.66	0.8539
std_part	0.1228	0.079	1.5539	0.1202	-0.0321	0.2777

B) Traveler Type

Table B1 – Details of alternatives

Alternatives	Description
unique2 == 0	The person is unique traveler
unique2 == 1	The person is non-unique traveler

Table B2 - Details of independent variables

Variables	Description
Intercept	Intercept
retired	1 if retired, 0 otherwise
nonwrk	1 if non-worker other than retired, 0 otherwise
age16to25	1 if age between 16 to 25; 0 otherwise
age26to35	1 if age between 26 to 35; 0 otherwise
vehdef	1 if number of vehicles in household is less than number of adults; 0 otherwise
persons_count	number of persons in household
driver	1 if driver, 0 otherwise
tranpass_true	1 if the person has a transit pass; 0 otherwise
wkhome	1 if the work location is home; 0 otherwise
std_full	1 if part-time student, 0 otherwise

Table B3 - Estimation of parameters

Parameters	Estimates	Std.Err.	z	P>|z|	[0.025	0975]
Intercept	3.1901	0.1287	24.786	0	2.9379	3.4424
retired	-0.2838	0.0798	-3.5546	0.0004	-0.4403	-0.1273
nonwrk	-0.8129	0.0723	-11.2488	0	-0.9546	-0.6713
age16to25	0.5139	0.1374	3.7407	0.0002	0.2446	0.7832
age26to35	0.3329	0.1086	3.0655	0.0022	0.1201	0.5458
vehdef	-0.3033	0.0662	-4.5787	0	-0.4331	-0.1735
persons_count	-0.1209	0.024	-5.0377	0	-0.1679	-0.0738
driver	-0.534	0.102	-5.2363	0	-0.7339	-0.3341
tranpass_true	0.2849	0.0732	3.8925	0.0001	0.1415	0.4284
wkhome	-0.5542	0.1208	-4.5892	0	-0.7909	-0.3175
std_full	0.9784	0.1295	7.5556	0	0.7246	1.2322

C) Day Pattern for Unique Travelers

Table C5 – Details of alternatives

Alternative	Description	Type
inihome	Initial home stay (first tour start time – survey start time)	Outside
finhome	Final home stay (survey end time – last tour end time)	Outside
interhome	Intermediate home stay (sum of home duration between tours)	Composite Inside
HB_work_dur	Time spent at work	Inside
HB_school_dur	Time spent at school	Inside
HB_meal_dur	Time spent for meal	Inside
HB_shop_dur	Time spent for shopping	Inside
HB_PerBus_dur	Time spent for personal business	Inside
HB_SocOth_dur	Time spent for social and recreational activities	Inside
HB_escort_dur	Time spent for escorting	Inside

Table C6 - Details of independent variables

Variable	Description
age_youth	1 if age between 16-25, 0 otherwise
age_senior	1 if age 65 and more, 0 otherwise
is_male	1 if male, 0 otherwise
transit_pass	1 if has pass, 0 otherwise
universitystd	1 if university student, 0 otherwise
retired	1 if retired, 0 otherwise
nonwkr	1 if non-worker, 0 otherwise (age >= 16)
wkhome	1 if work from home, 0 otherwise
workday_flex	1 if has some degree of flexibility, 0 otherwise
std16plus	1 if student and 16 plus, 0 otherwise
vlowinc	1 if income less than 25k, 0 otherwise
lowinc	1 if income less than 50k, 0 otherwise
only_adult	1 if only adult in the household, 0 otherwise
only_worker	1 if only worker in the household, 0 otherwise

Table C7 - Estimation of parameters ($P \leq 0.2$)

Variables	inihome	finhome	interhome	HB_work_dur	HB_school_dur	HB_meal_dur	HB_shop_dur	HB_PerBus_dur	HB_SocOth_dur	HB_escort_dur
ASC		0.4630	-6.7560	-6.2310	-7.2364	-7.9416	-7.6029	-7.3777	-7.9195	-8.0373
age_youth		-0.2069		-0.7268	0.9063	-0.2372	-0.3476		0.2292	-0.3709
age_senior			-0.1755		-1.7000			0.1197		-0.3064
is_male				0.1338		0.1479	-0.1527			-0.0750
transit_pass				0.4884	-1.2524	0.1742	0.1199	-0.1379	-0.2162	
universitystd		-0.1955		-0.1262	-0.2455	0.2429				
retired		-0.1560	-0.1212	-2.8086	-2.3530	0.5684	0.8923	0.4537	0.1576	
nonwrk		-0.2129	-0.1075	-1.6485	-2.1677	0.4936	0.7685	0.2154	0.1988	0.5138
wkhome		-0.1811	0.2026	0.1478	-2.0110	0.2649				0.3278
vlowinc			-0.1707	-0.2364	0.1867				-0.2527	
lowinc			-0.2956	-0.1839	0.1606	-0.3738	0.0686			
only_adult		-0.0698		0.3559	-0.8672		0.2128	-0.2825		-0.6659
only_worker				-0.2327	0.2581	-0.1164		0.0957		

Table C8 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000.0000	.	.	.	0
G01	-1000.0000	.	.	.	0
G02	-1000.0000	.	.	.	0
G03	4.3357	0.0252	171.9060	0.0000	0
G04	6.7922	0.0298	227.6800	0.0000	0
G05	6.7353	0.0448	150.3850	0.0000	0
G06	5.2772	0.0386	136.6590	0.0000	0
G07	4.6987	0.0306	153.4320	0.0000	0
G08	4.6725	0.0290	161.2360	0.0000	0
G09	5.4499	0.0413	132.0700	0.0000	0
G10	4.7118	0.0455	103.6170	0.0000	0
sigm	1.0000	.	.	.	1.3857

D) Day Pattern for Non-unique Travelers

Table D9 – Details of alternatives

Alternative	Description	Type
inihome	Initial home stay (first tour start time – survey start time)	Outside
finhome	Final home stay (survey end time – last tour end time)	Outside
interhome	Intermediate home stay (sum of home duration between tours)	Composite Inside
HB_work1_dur	Time spent at first work tour	Inside
HB_work2_dur	Time spent at second work tour	Inside
HB_school_dur	Time spent at school	Inside
HB_meal_dur	Time spent for meal	Inside
HB_shop1_dur	Time spent for first shopping tour	Inside
HB_shop2_dur	Time spent for second shopping tour	Inside
HB_PerBus1_dur	Time spent for first personal business tour	Inside
HB_PerBus2_dur	Time spent for second personal business tour	Inside
HB_SocOth_dur	Time spent for social and recreational activities	Inside
HB_escort1_dur	Time spent for first escort tour	Inside
HB_escort2_dur	Time spent for second escort tour	Inside

Table D10 - Details of independent variables

Variable	Description
ASC	Alternate Specific Constants
age_youth	1 if age between 16-25, 0 otherwise
age_senior	1 if age 65 and more, 0 otherwise
is_male	1 if male, 0 otherwise
transit_pass	1 if has pass, 0 otherwise
retired	1 if retired, 0 otherwise
wkhome	1 if work from home, 0 otherwise
only_worker	1 if only worker in the household, 0 otherwise
std16plus	1 if student and 16 plus, 0 otherwise
vlowinc	1 if income less than 25k, 0 otherwise
lowinc	1 if income less than 50k, 0 otherwise
workday_flex	1 if has some degree of flexibility, 0 otherwise
only_adult	1 if only adult in the household, 0 otherwise

Table D11 - Estimation of parameters ($P \leq 0.2$)

Variables	inihome	finhome	interhome	HB_work1_dur	HB_work2_dur	HB_school_dur	HB_meal_dur	HB_shop1_dur	HB_shop2_dur	HB_PerBus1_dur	HB_PerBus2_dur	HB_SocOth_dur	HB_escort1_dur	HB_escort2_dur
ASC		0.3454	-2.7933	-7.0452	-7.4572	-10.1999	-8.2293	-6.838	-7.4728	-6.4844	-7.0547	-8.2104	-6.0761	-6.0762
age_youth				0.5603							0.4999		-0.6786	-0.6786
age_senior									0.2658				-0.7389	-0.739
is_male				0.478	0.6717		0.5337	-0.1364					-0.2033	-0.2022
transit_pass				-0.4799	-0.5368			0.2963	0.3806				-0.2524	-0.2522
retired				-1.6493	-2.1291			0.7805	0.7534	0.4691	0.5556		-0.5517	-0.5521
wkhome								-1.2855		-1.0841				
only_worker			0.147	-0.1712	-0.2357				-0.2079				0.3304	0.3281
std16plus				-0.4294		2.345						0.5759		
vlowinc			0.4065	-0.4311	-0.8642				0.4137				0.4535	0.4534
lowinc					0.3486		-0.9785			-0.2324	-0.2539			
workday_flex			-0.0862	0.783	0.7444	-1.664					-0.1972		-0.3859	-0.3839
only_adult			-0.2938				0.3828			0.3943	0.6379	-1.0157		-1.0158

Table D12 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	1.866	0.1632	11.434	0	0
G04	5.6343	0.0767	73.469	0	0
G05	5.433	0.0836	64.955	0	0
G06	6.3171	0.4221	14.965	0	0
G07	4.6141	0.1313	35.148	0	-0.0001
G08	4.2758	0.071	60.23	0	0
G09	4.2264	0.0882	47.942	0	0
G10	4.1705	0.0627	66.56	0	0
G11	4.3609	0.0787	55.384	0	0
G12	4.91	0.1381	35.541	0	0
G13	3.5878	0.0651	55.073	0	-0.0001
G14	3.5892	0.0651	55.093	0	0.0001
sigm	1	.	.	.	1.9124

E) Zero Work-based Subtour

Table E1 – Details of alternatives

Alternatives	Description
zero_subtour == 0	The home-based work tour has subtours
zero_subtour == 1	The home-based work tour does not have subtour

Table E2 - Details of independent variables

Variables	Description
Intercept	Intercept
retired	1 if retired, 0 otherwise
nonwrk	1 if non-worker other than retired, 0 otherwise
age36to45	1 if age between 36 to 45; 0 otherwise
persons_count	number of persons in household
driver	1 if driver, 0 otherwise
tranpass_true	1 if the person has a transit pass; 0 otherwise
std_full	1 if part-time student, 0 otherwise
tour_duration	duration of parent home-based work tour (in minute)

Table E3 - Estimation of parameters

Parameters	Estimates	Std.Err.	z	P>|z|	[0.025	0975]
Intercept	4.2424	0.276	15.3693	0	3.7014	4.7834
retired	1.2758	0.5914	2.1573	0.031	0.1167	2.435
nonwrk	1.2594	0.3897	3.2317	0.0012	0.4956	2.0233
age36to45	-0.2253	0.0846	-2.6625	0.0078	-0.3911	-0.0594
persons_count	0.0414	0.0273	1.5181	0.129	-0.0121	0.0949
driver	-0.5627	0.2279	-2.4689	0.0136	-1.0094	-0.116
tranpass_true	-0.2152	0.0761	-2.8286	0.0047	-0.3644	-0.0661
std_full	0.8066	0.3194	2.5251	0.0116	0.1805	1.4327
tour_duration	-0.0033	0.0002	-15.9348	0	-0.0037	-0.0029

F) Work-based Subtour Pattern

Table F13 – Details of alternatives

Alternative	Description	Type
initwrk	Initial work stay	Outside
finwrk	Final work stay	Outside
fintrp	Return to workplace trip duration	Composite Inside
wk_epoch	Trip duration to the stop + Work stop dwell time	Inside
ml_epoch	Trip duration to the stop + Meal stop dwell time	Inside
sh_epoch	Trip duration to the stop + Shop stop dwell time	Inside
pb_epoch	Trip duration to the stop + Personal Business stop dwell time	Inside
so_epoch	Trip duration to the stop + Social and Others stop dwell time	Inside
es_epoch	Trip duration to the stop + Escort stop dwell time	Inside

Table F14 - Details of independent variables

Variable	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_youth	1 if age is between 16-25, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
empl_license	1 if the person is employed and has driver license, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
transit_pass	1 if has transit pass, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
tour_count	Number of tours made by the person for that person-day
md_SOV	1 if mode is SOV, 0 otherwise
md_oCarpool	1 if mode is carpool, 0 otherwise
md_WalkBike	1 if mode is walking/biking, 0 otherwise
md_transit	1 if mode is transit, 0 otherwise
trvlr_type	1 if travel is unique, 0 if non-unique

Table F15 - Estimation of parameters (P ≤ 0.2)

Variables	initwrk	finwrk	fintrp	wk_epoch	ml_epoch	sh_epoch	pb_epoch	so_epoch	es_epoch
ASC		-0.1605	8.8116	-7.4398	-5.5464	-7.7872	-6.5318	-7.6547	-8.1843
is_male			0.1608		0.3236				
age_youth				1.6037					
age_senior							0.7884		
workday_flex		0.1785							
empl_license						-0.7604			-1.697
jobs1plus			0.4001	0.5909				1.0349	1.0914
transit_pass								-0.9369	
op_veh			-0.1358						
only_worker		0.1268							
tour_count						0.2552			0.6904
md_SOV				0.7348		1.1894		-0.9423	-1.1127
md_oCarpool					0.6414		-1.0984	-0.6586	
md_WalkBike			-0.468			0.7341			-3.2627
md_transit		-1.6766	1.0326						
trvlr_type									1.5184

Table F16 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-11.8289	42.6391	-0.277	0.7815	0
G04	4.7377	0.1742	27.194	0	0
G05	3.1437	0.076	41.353	0	0
G06	3.2501	0.1461	22.245	0	0
G07	3.61	0.1236	29.2	0	0
G08	4.2219	0.2919	14.464	0	0
G09	2.6888	0.3522	7.634	0	0
sigm	1	.	.	.	1.1501

G) Intermediate Stop Generation for Work

Table G17 – Details of alternatives

Alternatives	Description	Type
tt_pa	Travel time to primary activity	Outside
pa	Primary activity	Outside
rh	Return home	Outside
wo1_dur	Time spent for the first work stop	Inside
wo2_dur	Time spent for the second work stop	Inside
wo3_dur	Time spent for the third work stop	Inside
sc_dur	Time spent for school at the stop	Inside
ml1_dur	Time spent for first meal stop	Inside
ml2_dur	Time spent for the second meal stop	Inside
sh1_dur	Time spent for the first shop stop	Inside
sh2_dur	Time spent for the second shop stop	Inside
pb1_dur	Time spent for the first personal business stop	Inside
pb2_dur	Time spent for the second personal business stop	Inside
so_dur	Time spent for social and other activities at the stop	Inside
es1_dur	Time spent for the first escort stop	Inside
es2_dur	Time spent for the second escort stop	Inside
es3_dur	Time spent for the third escort stop	Inside

Table G18 - Details of independent variables

Variables	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_adult	1 if age is between 25-64, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
driver_license	1 if has driver license, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
transit_pass	1 if has transit pass, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
only_adult	1 if the person is the only adult, 0 otherwise
nonstudent	1 if the person is nonstudent, 0 otherwise
retired	1 if the person is retired, 0 otherwise
part_std	1 if the person is part-time student, 0 otherwise
vlowinc	1 if the household income is less than 25k, 0 otherwise
lowinc	1 if the household income is less than 50k, 0 otherwise
wkhome	1 if the person works from home, 0 otherwise
tdur_3to6	1 if the tour duration is between 3 to 6 hours, 0 otherwise
trans_sub	1 if the person gets transit subsidy, 0 otherwise
tour_trip_count_2	1 if there are more than 2 trips in a tour, 0 otherwise
onevehperad	1 if there is more than 1 vehicle per adult, 0 otherwise

Table G19 - Estimation of parameters (P ≤ 0.2)

Variables	tt_pa	pa	rh	wo1_dur	wo2_dur	wo3_dur	sc_dur	ml1_dur	ml2_dur	sh1_dur	sh2_dur	pb1_dur	pb2_dur	so_dur	es1_dur	es2_dur	es3_dur
ASC		2.6337	-0.2142	-5.419	-6.4288	-8.85	-3.7956	-4.2565	-6.6517	-4.1672	-6.4031	-3.3661	-5.5802	-5.3171	-2.2275	-3.5285	-5.2318
is_male				0.2291	0.3723	0.8025				-0.2928	-0.2924	-0.2131	-0.2598		-0.2357	-0.3333	-0.7
age_adult							-1.2218			0.2124				-0.6847			2.1172
age_senior		-0.2642												-0.7259	-0.8987	-1.2376	
driver_license											0.4887	-0.4543		0.6403	-1.0577	-2.7902	-2.7729
jobs1plus		-0.7197	0.0815	1.1016	1.4139	1.5064			0.4825						-0.4021	-0.2802	
transit_pass		-0.2356		-0.2715	-0.5521					-0.3679			-0.446		-0.3984	-0.2159	
op_veh				0.1789	0.2262	1.0231				0.1324		0.1632			-0.3964	-0.5633	-0.8075
only_worker																	
only_adult			-0.1101	-0.2381			-2.4727			0.2551		-0.194			-0.908	-0.4665	-2.7593
nonstudent		0.3131		0.6115			-4.3379									1.9587	
retired		-0.8863		0.7296			1.6512			0.5557	1.2994				-0.664		
part_std		0.235		0.7128							0.4379					2.1377	
vlowinc				0.5103				-0.4413									
lowinc															0.1696	0.3553	
wkhome				0.4211	0.8224			0.4944							0.7112		
tdur_3to6		-0.2765		0.1911			-1.8904			0.6518	0.7464	0.3289	0.3524		0.2173		
trans_sub		-0.1646						-0.4397				-0.2418	-0.7891		-0.6354	-0.6939	
tour_trip_count_2		-0.0961	0.2208	-10.357	-8.7318	-6.965	-7.1074	-10.3099	-7.6619	-10.605	-8.6255	-10.9463	-8.5364	-9.397	-10.7469	-9.5465	-7.4593
onevehperad												0.131			-0.1255		

Table G20 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-1000	.	.	.	0
G04	5.3252	0.0828	64.306	0	0
G05	4.2839	0.1231	34.791	0	0
G06	4.364	0.2577	16.935	0	0
G07	6.1807	0.3731	16.565	0	0
G08	3.8054	0.0605	62.881	0	0
G09	4.3332	0.1825	23.741	0	0
G10	3.6415	0.0521	69.894	0	0
G11	3.5023	0.1231	28.46	0	0
G12	3.8699	0.0502	77.13	0	0
G13	3.539	0.1241	28.523	0	0
G14	4.8653	0.107	45.467	0	0
G15	2.9063	0.0509	57.047	0	0
G16	3.1539	0.0815	38.696	0	0
G17	3.0298	0.1872	16.181	0	0
sigm	1	.	.	.	1.2043

H) Intermediate Stop Generation for School

Table H21 – Details of alternatives

Alternatives	Description	Type
tt_pa	Travel time to primary activity	Outside
pa	Primary activity	Outside
rh	Return home	Outside
sc_dur	Time spent for school at the stop	Inside
ml_dur	Time spent for meal at the stop	Inside
sh_dur	Time spent for shop at the stop	Inside
pb_dur	Time spent for personal business at the stop	Inside
so_dur	Time spent for social and other activities at the stop	Inside
es_dur	Time spent for escort at the stop	Inside

Table H22 - Details of independent variables

Variables	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_adult	1 if age is between 25-64, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
driver_license	1 if has driver license, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
transit_pass	1 if has transit pass, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
only_adult	1 if the person is the only adult, 0 otherwise
nonstudent	1 if the person is nonstudent, 0 otherwise
retired	1 if the person is retired, 0 otherwise
part_std	1 if the person is part-time student, 0 otherwise
vlowinc	1 if the household income is less than 25k, 0 otherwise
lowinc	1 if the household income is less than 50k, 0 otherwise
wkhome	1 if the person works from home, 0 otherwise
tdur_3to6	1 if the tour duration is between 3 to 6 hours, 0 otherwise
trans_sub	1 if the person gets transit subsidy, 0 otherwise
tour_trip_count_2	1 if there are more than 2 trips in a tour, 0 otherwise
onevehperad	1 if there is more than 1 vehicle per adult, 0 otherwise

Table H23 - Estimation of parameters (P ≤ 0.2)

Variables	tt_pa	pa	rh	sc_dur	ml_dur	sh_dur	pb_dur	so_dur	es_dur
ASC		3.0939	0.0769	-5.6233	-5.3975	-6.0905	-4.9405	-5.462	-4.5905
is_male									
age_adult		-0.7795	-0.475	-1.3616				-1.4172	-0.4644
age_senior		-0.4246							
driver_license		-0.2293					-0.3525		-0.5809
jobs1plus							0.6812		
transit_pass		-0.3839							
op_veh					0.3433				
only_worker									
only_adult				0.7487		0.6263		0.5825	
nonstudent		-0.4426							
retired								1.1777	
part_std		-0.3017		-1.1234			-0.5245		
vlowinc									
lowinc					-0.6817				0.2119
wkhome									
tdur_3to6		-0.4997				0.6533		-1.4664	
trans_sub		-0.4887			-1.4125				
tour_trip_count_2		0.5111							
onevehperad						0.3482	0.281		

Table H24 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-1000	.	.	.	0
G04	7.0901	0.3938	18.005	0	0
G05	3.9026	0.1383	28.214	0	0
G06	3.812	0.1587	24.02	0	0
G07	4.6189	0.127	36.378	0	0
G08	4.987	0.1713	29.115	0	0
G09	2.7942	0.0957	29.206	0	0
sigm	1	.	.	.	1.1687

I) Intermediate Stop Generation for Meal

Table I25 – Details of alternatives

Alternatives	Description	Type
tt_pa	Travel time to primary activity	Outside
pa	Primary activity	Outside
rh	Return home	Outside
ml_dur	Time spent for meal at the stop	Inside
sh_dur	Time spent for shop at the stop	Inside
pb1_dur	Time spent for the first personal business stop	Inside
pb2_dur	Time spent for the second personal business stop	Inside
so_dur	Time spent for social and other activities at the stop	Inside

Table I26 - Details of independent variables

Variables	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_youth	1 if age is between 16-25, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
transit_pass	1 if has transit pass, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
only_adult	1 if the person is the only adult, 0 otherwise
retired	1 if the person is retired, 0 otherwise
part_std	1 if the person is part-time student, 0 otherwise
vlowinc	1 if the household income is less than 25k, 0 otherwise
lowinc	1 if the household income is less than 50k, 0 otherwise
wkhome	1 if the person works from home, 0 otherwise
tdur_3to6	1 if the tour duration is between 3 to 6 hours, 0 otherwise
trans_sub	1 if the person gets transit subsidy, 0 otherwise
tour_trip_count_2	1 if there are more than 2 trips in a tour, 0 otherwise
workday_flex	1 if the person has flexibility in workday, 0 otherwise
std16below	1 if student and below 16years old, 0 otherwise

Table I27 - Estimation of parameters (P ≤ 0.2)

Variables	tt_pa	pa	rh	ml_dur	sh_dur	pb1_dur	pb2_dur	so_dur
ASC		0.4343	-0.4096	-5.6418	-4.8506	-3.8811	-5.0888	-4.88
is_male								
age_youth						-0.6606		
age_senior					0.2659	0.2138		
jobs1plus								
transit_pass				-0.4684		-0.2321	-0.3745	
op_veh						0.3293		0.3038
only_worker							-0.5704	
only_adult								
retired								
part_std		-0.2468			-0.6393		-1.3707	
vlowinc								
lowinc								
wkhome							1.7214	
tdur_3to6		0.3124		-0.6485				0.2034
trans_sub								
tour_trip_count_2		1.3555	0.8868					
workday_flex						-0.1777	-0.3832	
std16below								

Table I28 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-1000	.	.	.	0
G04	3.7761	0.2061	18.319	0	0
G05	3.7918	0.1198	31.641	0	0
G06	4.8827	0.1111	43.952	0	0
G07	4.218	0.1709	24.687	0	0
G08	6.3068	0.2501	25.213	0	0
sigm	1	.	.	.	1.1259

J) Intermediate Stop Generation for Shopping

Table J29 – Details of alternatives

Alternatives	Description	Type
tt_pa	Travel time to primary activity	Outside
pa	Primary activity	Outside
rh	Return home	Outside
ml_dur	Time spent for meal at the stop	Inside
sh1_dur	Time spent for the first shopping stop	Inside
sh2_dur	Time spent for the second shopping stop	Inside
pb1_dur	Time spent for the first personal business stop	Inside
pb2_dur	Time spent for the second personal business stop	Inside
so_dur	Time spent for social and other activities at the stop	Inside

Table J30 - Details of independent variables

Variables	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_adult	1 if age is between 25-64, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
driver_license	1 if has driver license, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
transit_pass	1 if has transit pass, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
only_adult	1 if the person is the only adult, 0 otherwise
nonstudent	1 if the person is nonstudent, 0 otherwise
retired	1 if the person is retired, 0 otherwise
part_std	1 if the person is part-time student, 0 otherwise
vlowinc	1 if the household income is less than 25k, 0 otherwise
lowinc	1 if the household income is less than 50k, 0 otherwise
wkhome	1 if the person works from home, 0 otherwise
tdur_3to6	1 if the tour duration is between 3 to 6 hours, 0 otherwise
trans_sub	1 if the person gets transit subsidy, 0 otherwise
tour_trip_count_2	1 if there are more than 2 trips in a tour, 0 otherwise
onevehperad	1 if there is more than 1 vehicle per adult, 0 otherwise

Table J31 - Estimation of parameters (P ≤ 0.2)

Variables	tt_pa	pa	rh	ml_dur	sh1_dur	sh2_dur	pb1_dur	pb2_dur	so_dur
ASC		0.731	-0.3387	-5.0863	-3.7434	-5.4331	-3.8653	-5.4484	-5.1603
is_male		-0.2154							
age_adult							0.4652	0.345	-0.4244
age_senior					0.1609		0.4448		-0.7499
driver_license		-0.0975							
jobs1plus		-0.1158					0.1697		
transit_pass		-0.1457							
op_veh				0.3074					
only_worker									
only_adult			0.1417				0.205	0.6554	
nonstudent							-0.226		0.37
retired							0.3209	0.613	
part_std									
vlowinc		-0.1648				-0.531	-0.3293	-0.4309	
lowinc		0.1599					0.1428		
wkhome									
tdur_3to6							0.1572		
trans_sub					0.4335				
tour_trip_count_2		1.0302	0.9872						
onevehperad				-0.2705			0.1525		0.3983

Table J32 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-1000	.	.	.	0
G04	3.7537	0.1272	29.51	0	0
G05	4.0627	0.071	57.213	0	0
G06	3.4042	0.1333	25.538	0	0
G07	4.3475	0.0742	58.609	0	0
G08	3.4634	0.1132	30.588	0	0
G09	6.5152	0.3315	19.654	0	0
sigm	1	.	.	.	1.2921

K) Intermediate Stop Generation for Social and Recreational Activities

Table K33 – Details of alternatives

Alternatives	Description	Type
tt_pa	Travel time to primary activity	Outside
pa	Primary activity	Outside
rh	Return home	Outside
pb_dur	Time spent for personal business at the stop	Inside
so_dur	Time spent for social and other activities at the stop	Inside

Table K34 - Details of independent variables

Variables	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_youth	1 if age is between 16-25, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
workday_flex	1 if the person has flexibility in workday, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
trans_sub	1 if the person gets transit subsidy, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
only_adult	1 if the person is the only adult, 0 otherwise
retired	1 if the person is retired, 0 otherwise
wkhome	1 if the person works from home, 0 otherwise
vlowinc	1 if the household income is less than 25k, 0 otherwise
lowinc	1 if the household income is less than 50k, 0 otherwise
part_std	1 if the person is part-time student, 0 otherwise
std16below	1 if student and below 16years old, 0 otherwise

Table K35 - Estimation of parameters (P ≤ 0.2)

Variables	tt_pa	pa	rh	pb_dur	so_dur
ASC		1.4848	-0.0916	-5.863	-5.9983
is_male					-0.3073
age_youth		0.3086			
age_senior		0.2161		0.4891	
workday_flex					
jobs1plus		-0.1772			
trans_sub					
op_veh		0.152			0.3952
only_worker					
only_adult				0.5109	
retired		-0.3051			0.3922
wkhome		-1.226		1.3521	
vlowinc		-0.2925			0.5896
lowinc					
part_std		0.2159			
std16below		0.6119			

Table K36 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-1000	.	.	.	0
G04	4.5353	0.1914	23.696	0	0
G05	6.2171	0.3313	18.763	0	0
sigm	1	.	.	.	0.5967

L) Intermediate Stop Generation for Personal Business

Table L37 – Details of alternatives

Alternatives	Description	Type
tt_pa	Travel time to primary activity	Outside
pa	Primary activity	Outside
rh	Return home	Outside
pb_dur	Time spent for personal business at the stop	Inside
so_dur	Time spent for social and other activities at the stop	Inside

Table L38 - Details of independent variables

Variables	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_youth	1 if age is between 16-25, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
workday_flex	1 if the person has flexibility in workday, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
trans_sub	1 if the person gets transit subsidy, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
only_adult	1 if the person is the only adult, 0 otherwise
retired	1 if the person is retired, 0 otherwise
wkhome	1 if the person works from home, 0 otherwise
vlowinc	1 if the household income is less than 25k, 0 otherwise
lowinc	1 if the household income is less than 50k, 0 otherwise
part_std	1 if the person is part-time student, 0 otherwise
std16below	1 if student and below 16years old, 0 otherwise
transit_pass	1 if has transit pass, 0 otherwise
tdur_3to6	1 if the tour duration is between 3 to 6 hours, 0 otherwise

Table L39 - Estimation of parameters (P ≤ 0.2)

Variables	tt_pa	pa	rh	pb_dur	so_dur
ASC		0.8541	-0.0415	-5.6916	-7.13
is_male		-0.1027			-0.4999
age_youth		0.258			
age_senior		0.2043			0.849
workday_flex		0.1388		0.381	
jobs1plus		-0.1501		0.2419	
trans_sub				-0.6859	
op_veh		0.1976			0.5779
only_worker		0.1492			
only_adult		-0.1806			
retired		-0.3235		0.5273	
wkhome					
vlowinc				-0.5325	
lowinc				0.3295	-0.8746
part_std		0.1925			
std16below		0.6485			1.0038
transit_pass		-0.0984			
tdur_3to6		0.717	-0.2136	0.4591	0.8275

Table L40 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-1000	.	.	.	0
G04	5.8211	0.2259	25.771	0	0
G05	4.706	0.2529	18.609	0	0
sigm	1	.	.	.	0.6105

M) Intermediate Stop Generation for Escort

Table M41 – Details of alternatives

Alternatives	Description	Type
tt_pa	Travel time to primary activity	Outside
pa	Primary activity	Outside
rh	Return home	Outside
ml_dur	Time spent for meal at the stop	Inside
sh1_dur	Time spent for the first shop stop	Inside
sh2_dur	Time spent for the second shop stop	Inside
pb1_dur	Time spent for the first personal business stop	Inside
pb2_dur	Time spent for the second personal business stop	Inside
so_dur	Time spent for social and other activities at the stop	Inside
es_dur	Time spent for escort at the stop	Inside

Table M42 - Details of independent variables

Variables	Description
ASC	Alternate Specific Constants
is_male	1 if male, 0 otherwise
age_adult	1 if age is between 25-64, 0 otherwise
age_senior	1 if age is 65 or more, 0 otherwise
driver_license	1 if has driver license, 0 otherwise
jobs1plus	1 if has more than 1 job, 0 otherwise
transit_pass	1 if has transit pass, 0 otherwise
op_veh	1 if there are more than 2 operational vehicles, 0 otherwise
only_worker	1 if the person is the only worker, 0 otherwise
only_adult	1 if the person is the only adult, 0 otherwise
nonstudent	1 if the person is nonstudent, 0 otherwise
retired	1 if the person is retired, 0 otherwise
part_std	1 if the person is part-time student, 0 otherwise
vlowinc	1 if the household income is less than 25k, 0 otherwise
lowinc	1 if the household income is less than 50k, 0 otherwise
wkhome	1 if the person works from home, 0 otherwise
tdur_3to6	1 if the tour duration is between 3 to 6 hours, 0 otherwise
trans_sub	1 if the person gets transit subsidy, 0 otherwise
tour_trip_count_2	1 if there are more than 2 trips in a tour, 0 otherwise
onevehperad	1 if there is more than 1 vehicle per adult, 0 otherwise

Table M43 - Estimation of parameters (P ≤ 0.2)

Variables	tt_pa	pa	rh	ml_dur	sh1_dur	sh2_dur	pb1_dur	pb2_dur	so_dur	es_dur
ASC		-1.1456	-0.0855	-4.9486	-4.0807	-6.0293	-3.4908	-5.9847	-5.118	-4.2335
is_male		-0.1616			-0.3896		-0.2472			
age_adult										
age_senior					0.3049					0.2426
driver_license										
jobs1plus					-0.3821					
transit_pass										
op_veh										0.1598
only_worker										
only_adult							-0.3134		0.7494	
nonstudent							-0.6548	-0.4744	-0.4065	
retired		-0.1762						0.3909		
part_std							-0.5084			
vlowinc										
lowinc				-1.0057		0.6841	-0.3338			
wkhome		0.4084					0.9752			
tdur_3to6				1.4152			1.0489	1.49	1.5318	0.5919
trans_sub										
tour_trip_count_2										
onevehperad		0.2107								

Table M44 - Estimation of satiation parameters

Parameters	Estimates	StdErr	EstSE	P	Gradient
D01	-1000	.	.	.	0
G01	-1000	.	.	.	0
G02	-1000	.	.	.	0
G03	-1000	.	.	.	0
G04	4.4834	0.1258	35.652	0	0
G05	4.1719	0.103	40.491	0	0
G06	3.6838	0.1842	20.002	0	0
G07	4.7655	0.1095	43.537	0	0
G08	4.0128	0.2005	20.013	0	0
G09	6.0704	0.2477	24.509	0	0
G10	2.9897	0.0866	34.518	0	0
sigm	1	.	.	.	0.9722