Modeling the Role and Influence of Children in

Household Activity-Based Travel Model Systems

by

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ABSTRACT

Rapid developments are occurring in the arena of activity-based microsimulation models. Advances in computational power, econometric methodologies and data collection have all contributed to the development of microsimulation tools for planning applications. There has also been interest in modeling child daily activity-travel patterns and their influence on those of adults in the household using activity-based microsimulation tools. It is conceivable that most of the children are largely dependent on adults for their activity engagement and travel needs and hence would have considerable influence on the activity-travel schedules of adult members in the household. In this context, a detailed comparison of various activity-travel characteristics of adults in households with and without children is made using the National Household Travel Survey (NHTS) data. The analysis is used to quantify and decipher the nature of the impact of activities of children on the daily activity-travel patterns of adults. It is found that adults in households with children make a significantly higher proportion of high occupancy vehicle (HOV) trips and lower proportion of single occupancy vehicle (SOV) trips when compared to those in households without children. They also engage in more serve passenger activities and fewer personal business, shopping and social activities.

A framework for modeling activities and travel of dependent children is proposed. The framework consists of six sub-models to simulate the choice of going to school/pre-school on a travel day, the dependency status of the child, the activity type, the destination, the activity duration, and the joint activity engagement with an accompanying adult. Econometric formulations such as binary probit and multinomial logit are used to obtain behaviorally intuitive models that predict children's activity skeletons. The model framework is tested using a 5% sample of a synthetic population of children for Maricopa County, Arizona and the resulting patterns are validated against those found in NHTS data. Microsimulation of these dependencies of children can be used to constrain the adult daily activity schedules. The deployment of this framework prior to the simulation of adult non-mandatory activities is expected to significantly enhance the representation of the interactions between children and adults in activity-based microsimulation models.

Dedicated to my Father, Mother and Sister

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1. INTRODUCTION

1.1. Motivation

Over the past few decades, there has been a steady shift towards activity-based approaches for travel demand modeling (Kitamura 1988; Jones et al. 1990; Axhausen and Garling 1992; Bhat and Koppelman 1993; Ben-Akiva and Bowman 1998). Activity-based approaches treat travel as a derived demand i.e., a demand arising from the need to pursue activities distributed in time and space. The pursuit of activities is invariably subject to certain spatial and temporal constraints (Hagerstrand 1970). Thus, activity-based travel demand models are not only sensitive to policy interventions that may have an effect on travel choices but also to those influencing activity engagement patterns. The variation in times and locations at which activities are pursued would also lead to variation in travel demand on the transportation network. For example, imposing congestion pricing in a certain region may not only change the times during which certain activities are pursued but also might move activity locations out of the region. The full range of advantages of an activity-based approach to travel demand modeling and forecasting can be found in various studies that have been made in the past (Axhausen and Garling 1992; Kitamura 1996; Lemp et al. 2007).

Activity-based models need to be estimated and implemented at a disaggregate level. In other words, activity-based models operate at the level of each individual person in the region for which travel demand is being modeled. Travel demand is generated through the synthesis of spatially and temporally disparate activity episodes for each of the individual persons in the system. Both activity and travel episodes pursued by people are not always solo in nature. People often engage in joint activity and travel episodes which involve more than one person. In such joint activity and travel engagement cases, it can be expected that activity-travel patterns of some people may both affect and be affected by activity-travel patterns of other people. This variation in activity-travel engagement patterns due to interactions and interdependencies among different activity schedules of people is particularly significant among the members of a household. Evidence of the considerable magnitude of these interactions has been reported in some recent studies (Vovsha et al. 2003; Vovsha et al. 2004).

One can conceive of numerous occasions in a multi-person household, during which interactions among household members affecting travel and activity engagement patterns can be observed. One example would be the sharing of common household responsibilities such as shopping for groceries where the activity of shopping may be assigned to certain household member(s) who would then have to cater to shopping needs of the remaining household members. To achieve this, the responsible household members may have to reschedule and/or relocate some of their individual activities or in an extreme case, may have to refrain from engaging in those activities altogether. Another example would be a social or a family visit activity where a particular set of household members may need to travel to meet and socialize with common relatives or friends. Again, each of the involved household members may have to accommodate the schedules of the other involved members so as to make the social visit happen. A special kind of interaction among household members occurs in the case where there are children present. This is special due to the reason that children tend to be more dependent on the adult members of the household for pursuing activities at spatially distant locations than adults. It can be deduced from the importance of raising children and taking care of their needs as to how drastically they can affect the travel and activity engagement patterns of adults in a household.

There have been some recent studies looking into various activity-travel dimensions of children (Vovsha and Petersen 2005; Copperman and Bhat 2007; Sener et al. 2008; Yarlagadda and Srinivasan 2008; Paleti et al. 2010). However, most of these were either exploratory in nature or focused only on certain adult-child interactions such as escorting to and from school. In addition, literature on the effect of child activity-travel patterns on those of the adults is still in its infancy. Traditional activity-based models have generally included variables pertaining to the presence and characteristics of children as explanatory variables to account for child-adult interactions in a household.

In this context, it would be interesting to analyze the impact of children on the adult activity-travel patterns on a broader scale. A thorough comparison of the activity-travel patterns of adults living in households with and without children would be particularly useful to infer about the magnitude and extent of the constraints and dependencies imposed due to the presence of children. Though there have been some studies published on the activities pursued by children and how they affect the activities and travel patterns of adult household members, much remains to be done. An extensive analysis of how children affect the activity travel patterns of households would offer further insights into the adult-child interactions.

Recent attempts to incorporate complex household interactions have been made within activity-based microsimulation frameworks. Rapid advances have been made in the area of microsimulation-based approaches where the activities and travel for every individual are simulated and the resulting disaggregate patterns are then aggregated to evaluate the aggregate response to a particular policy measure. This progress has accelerated due to several factors of which the primary ones are 1) the advent of high-performance computing systems without which the simulation run times would have been prohibitive, 2) the availability of detailed activity-travel data at the disaggregate level, and 3) advances in statistical and econometric modeling techniques. There is abundant literature on the advantages and benefits of using disaggregate microsimulation based approaches (Vovsha et al. 2002; Walker 2005; Lemp et al. 2007). These methods are capable of capturing individual heterogeneity which is lost when using aggregate modeling techniques. These models are also behaviorally consistent in that they recognize that it is only the individual changes that collectively lead to aggregate variation in travel demand.

Microsimulation is particularly useful for incorporating interactions among the behavioral units and inter-relationships across their various activity-travel choice processes. Instead of estimating a model capable of simultaneously predicting several activity-travel choice dimensions taking into account their interdependencies, microsimulation offers a convenient technique to simulate each of the individual choice processes in a behaviorally consistent sequence. Hence, activity-based microsimulation modeling framework is a powerful tool for analyzing the interactions between choice-making entities and the inter-relationships that exist among them.

Many activity-based models attempt to incorporate child interactions in simulating the activity-travel patterns of households by including the presence and characteristics of children as explanatory variables. Though this approach is simple and may explain interactions to a certain extent, it would be interesting to analyze this problem from the child-focused approach. There are certainly some activities that primarily need to be pursued by children. These activities are likely to constrain the schedules of adults in the household. After mandatory or subsistence activities, it is most likely that adults tend to the requirements of children in the household who are dependent on them for their activity-travel needs. These activities can also be categorized as maintenance activities but would have the highest priority among them. The development of models of child activity-travel dimensions that are likely to influence the adult activity-travel choices in a household would be of considerable significance to activity-based microsimulation models. These models may be deployed in any activity-based modeling framework to enhance the representation of child-activity travel patterns and their interdependencies with those of household adults.

1.2. Research Objectives

In the context of explicitly incorporating child activity-travel patterns in activity-based models, the objectives of this research are three-fold. First, the research aims to make a thorough comparison of activity and travel patterns of households with and without children. This would help shed light on the nature of the influence extended by the presence of children on the activity-travel patterns of households. The second objective is to develop a modeling framework that can be incorporated into activity-based models to take into account the impact of children's activity-travel choices on those of the household adults. The estimation of the different sub-models in the developed framework to predict the various daily activity-travel dimensions for children is a key. This set of models can be applied in an activity generation microsimulation framework where the other maintenance and discretionary activities of adults are generated after the simulation of travel to and from school and after-school activities of household children who need chauffeuring and/or activity participation from the adults. The third objective is to deploy the models developed in a microsimulation environment to test the validity and behavioral consistency of the resulting dependent activity skeletons of a sample population of dependent children.

1.3. Overview of the Methodology

To accomplish the first objective, travel data from the 2009 National Household Travel Survey (NHTS) is used to isolate joint household trips involving children. Activity and travel patterns of adults living in households with children are analyzed and compared to those living in households without children. For the second objective, a set of choice/decision components such as the daily decision of attending school, travel independence, after-school and joint activity engagement with household adults are tied together in a behaviorally consistent manner. Since this study looks at a series of activity-travel choice components, relatively practical model formulations have been estimated. A few models are rate-based probability models while others involve binary and multinomial logit formulations. The model framework is then implemented for a sample population of children using the OpenAMOS activity-based microsimulation model and the results are validated against NHTS data.

1.4. Organization of the Document

The remainder of the document is organized as follows. Chapter two reviews previous literature on activity-based microsimulation model frameworks that take into account household interactions with emphasis on adult-child interactions. Chapter three describes the data used in this effort. A comparative analysis of activity and travel characteristics of households with and without children is provided. Chapter four presents the modeling framework for incorporating child dependencies in the adult activity-travel generation process. The various sub-models and their linkages are described in detail. Chapter five provides estimated model specifications and their interpretations. Microsimulation results and validation for a test scenario are presented in chapter six. Conclusions and recommendations for future work are discussed in chapter seven.

2. BACKGROUND LITERATURE

This chapter has two sections. The first section presents recent literature on activity-based microsimulation model frameworks. It is intended to provide an overview of some of the approaches relevant to the current effort. A comprehensive review of all activity-based microsimulation model frameworks in the literature is beyond the scope of this research. The second section focuses on literature related to analyses and modeling approaches for children's activities. A review of the literature on household interactions involving children and incorporation of these interactions in activity-based microsimulation frameworks is also presented in detail.

2.1. Activity-Based Microsimulation Model Frameworks

As mentioned earlier, rapid advances have been made in data collection techniques, econometric modeling methodologies, and computational power. All of these advances have facilitated the development and implementation of activity-based microsimulation models on a large scale. Activity-based microsimulation models attempt to simulate daily activity-travel patterns for each individual in the system. A daily activity-travel pattern consists of a set of interspersed activity and travel episodes that a person can engage in throughout a whole day. An activity-based microsimulation model framework represents a mechanism using which all the activity and travel episodes that a person participates in can be both generated and scheduled. A framework defines a sequence of models which simulate the activity-travel episodes to obtain daily activity-travel patterns that are behaviorally consistent. The focus is on capturing the decision making process and the scheduling constraints that may exist appropriately. A system might simply use some rule-based heuristics or employ utility maximization approaches for generating the activity-travel patterns (Arentze et al. 2001). As the complexity of the decision making processes increases, conditional and hierarchical models may be used to take into account interactions and interdependencies among the various activity-travel decisions.

A considerable number of activity-based microsimulation model frameworks have been developed and implemented in the past few decades. The Activity-Mobility Simulator (AMOS) (Kitamura et al. 1996; Pendyala et al. 1998), the Prism Constrained Activity-Travel Simulator (PCATS) (Kitamura and Fujii 1998; Kitamura et al. 2008), ALBATROSS (Arentze and Timmermans 2001), TASHA (Miller and Roorda 2003), Florida's Activity Mobility Simulator (FAMOS) (Pendyala et al. 2005) are a few examples. Most of them first generate mandatory activities or tours such as those involving work and school since it can be expected that the daily activity-travel patterns are primarily shaped by them. Other non-mandatory activities (such as maintenance and discretionary) are scheduled around these fixed activities. The temporal constraints of mandatory activities are defined by time-space prism vertices (Kitamura et al. 2000; Pendyala et al. 2002). Once, the mandatory activity periods in a day are fixed, various discretionary and maintenance activities and their corresponding travel attributes are determined via econometric models run in a logical sequence. Non-mandatory activities represented by type, duration and location are generated on a continuous time-axis without violating the time-space prism constraints imposed by mandatory activities and also taking into account history dependencies (Kasturirangan et al. 2002). The models also involve the generation of various travel attributes for engaging in the simulated activities such as mode choice and start time. In this manner, generation of individual activities on continuous time-scale “evolves” into whole day activity-travel patterns for all the individuals in the system.

In other frameworks such as the Comprehensive Econometric Microsimulator for Daily Activity-travel Patterns (CEMDAP) described in Bhat et al. 2004, models represent activity-travel patterns as a set of tours (Ben-Akiva et al. 1996; Bowman and Ben-Akiva 2001). A tour is a set of trips linked together with start location of the first trip and end location of the last trip being the same. Hence, a tour consists of several activity and travel episodes. In these models, tour attributes such as tour type, mode, and number of stops by purpose are determined first before the simulation of episode level attributes such as stop locations and durations. Even though the unit of representation is slightly different, tour-based microsimulation models also ensure compliance with temporal and spatial constraints. Further details regarding different kinds of frameworks may be obtained from a recent study of various activity-based microsimulation model implementations in the US (Bowman and Bradley 2008). It provides a general classification of techniques of integration of various sub-models in activity-based model frameworks that have been recently used for travel forecasting based on hierarchy/conditionality and simultaneity/sequence. Potential strengths and weaknesses of each of approaches have also been compared.

2.2. Child Activities and Interactions with Adults

Activities pursued by children are of interest across multiple fields of study. Professionals in child development studies and behavioral sciences have found that child activity engagement patterns influence their learning ability, social behavior and engagement in school (Huebner and Mancini 2003; Darling 2005; Dotterer et al. 2007). There is growing concern among public health officials that decrease in the levels of physical activity among children is leading to an increase in obesity and cardiovascular diseases since there is evidence of strong correlations between the two (Transportation Research Board and Institute of Medicine 2005). In addition, evidence of linkages between built environment and physical activity levels of children has also been found (Copperman and Bhat 2007). Finally, travel demand modelers are interested in activity-travel engagement patterns of children since they invariably involve interdependencies and interactions with adults. Therefore, responses to transportation policy measures are not only composed of their direct impact on adults but also involve indirect effects due to adult-child interactions in households (McDonald 2005; Sener et al. 2008; Paleti et al. 2010).

Several studies published in the literature have stressed on the importance of modeling joint activity engagement and intra-household interactions and have shown that these considerably influence the activity-travel patterns of the household members (Gliebe and Koppelman 2002; Scott and Kanaroglou 2002; Vovsha et al. 2004; Srinivasan and Bhat 2005). Hence, ignoring them may lead to erroneous or biased forecasts in a policy application scenario analysis context. Most of the models developed so far have concentrated on activity-travel patterns of adults in the household and very few have looked at the activity-travel requirements of children and how they influence the patterns of the household adults. Vovsha et al. (2003) reported that joint activity participation does not necessarily translate into joint travel, especially in cases where children are involved. It was found that a significant amount of joint travel involved pure escorting kind of trips where household members transport other members to their activity locations without really engaging in activities jointly. In the daily activity-travel pattern generation hierarchy, the joint travel model was placed above the individual travel model with travel for engaging in manadatory activities still being given the highest priority. In travel mode choices for these activities, the single occupancy vehicle (SOV) mode is excluded. Siginificant amount of joint travel (from one-third to half of all home-based tours) has been reported. Joint tours have also been found to be significantly higher for non-mandatory activities than mandatory ones. Modeling of joint tours has been accomplished using a sequence of three choice models 1) joint tour frequency, 2) travel party composition, and 3) person participation in each tour for each of the household members. This set of joint travel models was implemented using a tour-based microsimulation framework.

Attempts have been made to study specific travel dimensions of children that may induce adult-child dependencies in a household. Yarlagadda and Srinivasan (2008) developed a mode choice model to and from school along with consideration of parental escort. The contributions of this study included simultaneous modeling of modes both to and from school along with parental escort roles as part of the mode choice decision. It was found that accommodation of household interaction effects was important for realistic policy evaluations. Specific explanatory factors such as work status and flexibility of work schedules of the child's mother and father were found to be significant. In addition, it was also reported that a considerable fraction of school children were being escorted by non-household members. However, incorporating these mode choice models into a framework that simulates the activity-travel patterns of all the adults in the household was beyond the scope of that work.

Vovsha and Petersen (2005) modeled the escorting of school children based on the different types of joint travel arrangements such as – shared ride, pure escorting, and no escort. This effort was a part of the regional travel model system being developed for the Atlanta Regional Commission (ARC) and focused on modeling joint travel rather than joint activity itself. Choices of joint travel arrangement and the specific household adult who would chauffeur the child (if needed) were explicitly enumerated and utility equations were constructed for each choice based on the utility/disutility caused by the choice of a particular arrangement to both the child and chauffeur. This was implemented in a tour-based framework and the choice of travel arrangement and household chauffeur was modeled for each half-tour made to school (inbound and outbound). It was found that joint travel arrangement to and from school was evenly divided between ridesharing and pure escorting. Gender roles and work statuses were reported significant. Females were more inclined to assume chauffeuring duties as opposed to males. Non-workers and part-time workers would undertake more escorting whereas, full-time workers were more inclined to undertake ridesharing arrangements. Regarding the placement of this model system in the overall hierarchy of the tour-based framework, it was noted that simulating these arrangements before simulating the commute mode choice would result in more realistic mode shift responses of commuters. The shift in commute mode may not be as elastic as it would appear without accounting for household interaction linkages; in that sense, the model without interaction effects would overestimate of the shift to transit mode in response to a transit friendly policy intervention. Only to and from school travel has been considered. There is undoubtedly a fair amount of joint travel involved for other activities after school which needs to be considered. Hence, it is important to analyze joint travel arrangements not only in terms of to and from school trips/tours but also to consider other after school discretionary activities that a child may pursue and for which an adult household member might be required for escorting. Another notable enhancement would be simultaneously determination of joint travel arrangements for multiple children (if present in a household). This stems from the expectation that if parents are escorting one child to school, they may also want to escort the other children in the household. These aspects of practical travel behavior are incorporated into the proposed dependency modeling framework in this research.

In a more recent study, Paleti et al. (2010) explored the after school activity engagement and time allocation patterns using the 2002 Child

Development Supplement of the Panel Study of Income Dynamics data. The need to understand the linkages from child activity-travel needs to the adult serve-passenger trips and joint activities has been emphasized. They also note that most of the earlier studies on activity-travel patterns have almost exclusively focused on adults. A framework for the generation and scheduling of children's post-school activity episodes is proposed. Generation and scheduling of both out-of-home and in-home activity episodes is done on a continuous time axis. All of the relevant activity-travel attributes of after-school activity-travel patterns of children are considered and characterized at various levels – pattern, activity-instance and episode. Pattern level attributes correspond to those broad patterns of activities that can be pursued immediately after the end of classes, at the end of a school episode and after reaching home. Activity-instance level attributes correspond to the activity purpose, destination and duration options that a child has. Episode level attributes pertain to mode-choice, time-of-day, specific spatial location and sequencing of episodes. It is noted that the joint modeling of all the above mentioned attributes would be prohibitive due to the sheer number of the resulting alternatives. Hence a behaviorally consistent approach that also makes sense practically is proposed. The hierarchy of the attributes at each level of representation determines the sequence in which they are predicted. They only focus on pattern level and activity-instance level attributes in the study, leaving episode level attributes for future work. It is noted that an activity can be either child-driven or adult-driven. However, in their study the authors assume activities to be child-driven mainly due to the objective of the study which is to model child activity-travel patterns irrespective of whether it is the adult or the child who drives them. The importance of school as an activity location after the end of classes is stressed upon to improve the characterization of children's after-school activity-travel pattern. A simple MNL model was employed for pattern level attributes whereas activity-instance level attributes were modeled using the Multiple Discrete Continuous Extreme Value (MDCEV) formulation. Overall, it was found that 55% of the children pursue at least one out-of-home activity after school which highlights the need to focus on children's after-school activity engagement. In addition to demographic variables, environmental and attitudinal variables pertaining to the child were found to be significant in explaining his or her after-school activity engagement patterns. Presence of an internet connection at home influences children to return home directly after school and stay at home. It was noted that the framework could be expanded to model activity accompaniment and joint trip making. There was a significant amount of activities also being pursued with non-household members. On the whole, the need for further efforts to integrate adult and child activity-travel patterns was emphasized.

3. DESCRIPTIVE ANALYSIS

This chapter starts with a brief description of the travel dataset used for the descriptive analysis – the National Household Travel Survey (NHTS). An analysis of the differences between households with and without children is done based on socio-demographics first. In addition, a wide range of activity and travel characteristics of adults living in both kinds of households are compared. These activity-travel patterns have been controlled for day of week with only Monday through Thursday travel considered to explore the influence of children on a typical weekday.

3.1. Data

The National Household Travel Survey (NHTS) records comprehensive trip data for all the trips made by respondents in a 24 hour period. This information is collected from all members of a household in the sample. Data from the most recent NHTS administered in 2009 are used for most of the analyses and modeling in this study. The total number of households including the national sample and samples from other add-on regions is 150,147 with around 324,000 persons in them. In the latest 2009 NHTS, accompanying household persons on a particular trip are not specified in the public use files, whereas in the 2001 NHTS dataset, this information is readily available. For this reason, analysis of certain joint trip making characteristics is done using the 2001 NHTS dataset. The sample size in 2001 NHTS is 69,817 households and approximately 160,000 persons. A frequency analysis (unweighted) on the 2009 data shows that 24.4% of the households had one or more children (0-17 years old) residing in them. If the household weights are applied, the proportion goes up to 34.4%. This considerable proportion of households with children provides the basis to compare and analyze the differences in activity-travel characteristics between households with and without children. The differences in activity and travel characteristics are compared only across adult members (18 years or older) of households since the primary objective of this analysis is to determine the effect of activities of children on the activity-travel patterns of adults. In other words, how are the activity engagement and travel patterns of adults living in households with children different from those living in households without children? If it is a fair assumption that the socio-demographic composition of the adults in the both kinds of household is not considerably different, a significant portion of the differences in the activity travel patterns of the two categories of adults may be attributed to the presence of children.

3.2. Comparison of Socio-Demographic Characteristics

Table 1 shows a comparison between some mean socio-demographics measures of households with and without children in them.

Table 1 Household Socio-Demographic Characteristics

	No Child in HH (N = 113,656)	Child in HH (N = 36,491)
Adults	1.81	2.15
Workers	0.75	1.46
Drivers	1.66	2.22
Vehicles	1.93	2.44
Daily trips	6.22	12.61

On average, households with children have a higher number of both vehicles and adults in them. Also, the mean values of number of drivers and workers are higher in case of households with children. In many of these aspects affecting travel demand, households with children seem to be larger than those without children. It may be argued that some children may also be drivers and/or workers which results in higher household mean values. Higher number of travel demand generating entities would lead to higher and more complex interactions among all these. The result can be seen in the average daily trip rate where households with children make twice as many trips as households without them. Another interesting pattern can be seen in Figure 1 which shows a comparison of the distributions of annual household income.

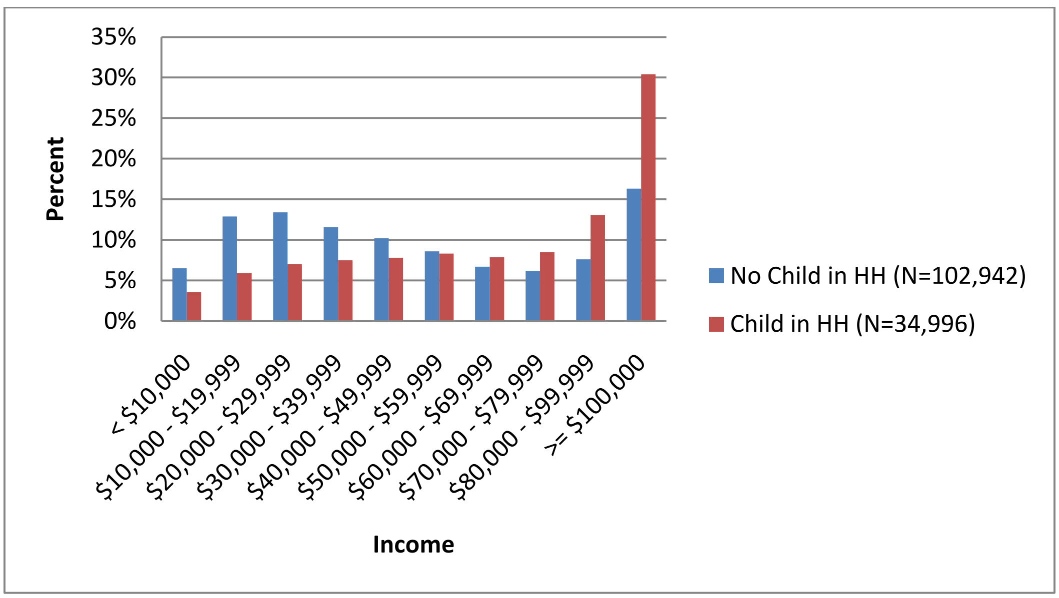

Fig. 1 Household Annual Income Distributions

The proportions of households with children are relatively lower in the lower income ranges and relatively higher in the higher income categories than those of households without children. In the highest income category (greater than $100,000 per year), the proportion of households with children is almost double that of households without them. This shows that households with children have relatively more earnings than those without children. Households with children are socio-demographically different from households without them which could result in significantly different activity engagement and travel patterns.

3.3. Comparison of Activity-Travel Characteristics

This section focuses on the difference in activity-travel characteristics of households with and without children present in them. As mentioned earlier, the characteristics of only adults in each category of households are compared. Figure 2 shows the daily mean person trip rates by purpose in both kinds of households. As mentioned earlier, these rates have been controlled for day of week and only Monday through Thursday travel days have been used in the calculations.

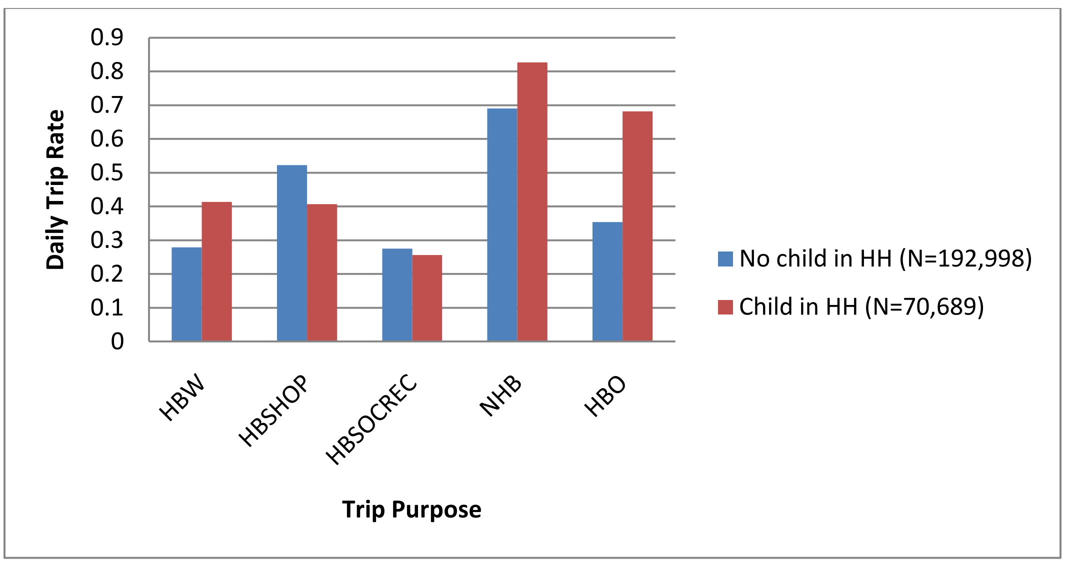

Fig. 2 Daily Mean Person Trip Rates by Purpose (Adults)

Adults living in households with children are making fewer home-based shopping and home-based social and recreational trips. A probable cause for this could be the additional constraints (both spatial and temporal) imposed by the presence of children in the household. On average, adults in households with children are making a higher number of home-based work trips per day. The reason for this is not readily apparent but on further investigation it was found that 73% of the adults in households with children are workers as opposed to only 44% of the adults in households without children. The higher percentage of workers among adults in households with children might be the cause for a higher daily mean home-based work trip rate. Also, these adults make a significantly higher number of non home-based and home-based other trips on a given weekday. A plausible explanation of this could be that these adults are required to make a significantly higher number of pick-up and drop-off trips to cater to the various activity and travel needs of children present in their households. A similar pattern was also found in the comparison of share of trips made by purpose shown in Figure 3.

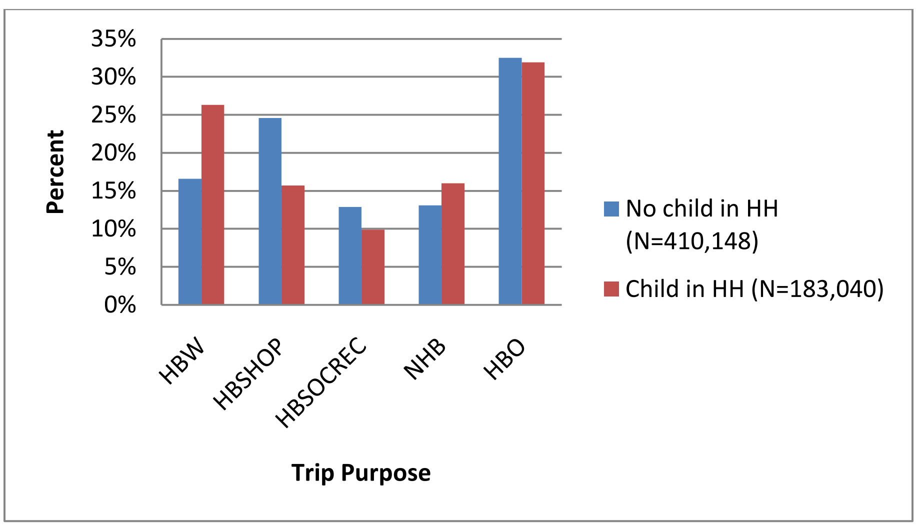

Fig. 3 Trip Purpose Distributions

A more detailed comparison is made by looking at the activity type distributions of the adults in both groups of households (Figure 4). They can be obtained by analyzing the finer categorization of the 'activity' purpose of the trips. In other words, what kind of an activity was pursued at the destination of a trip?

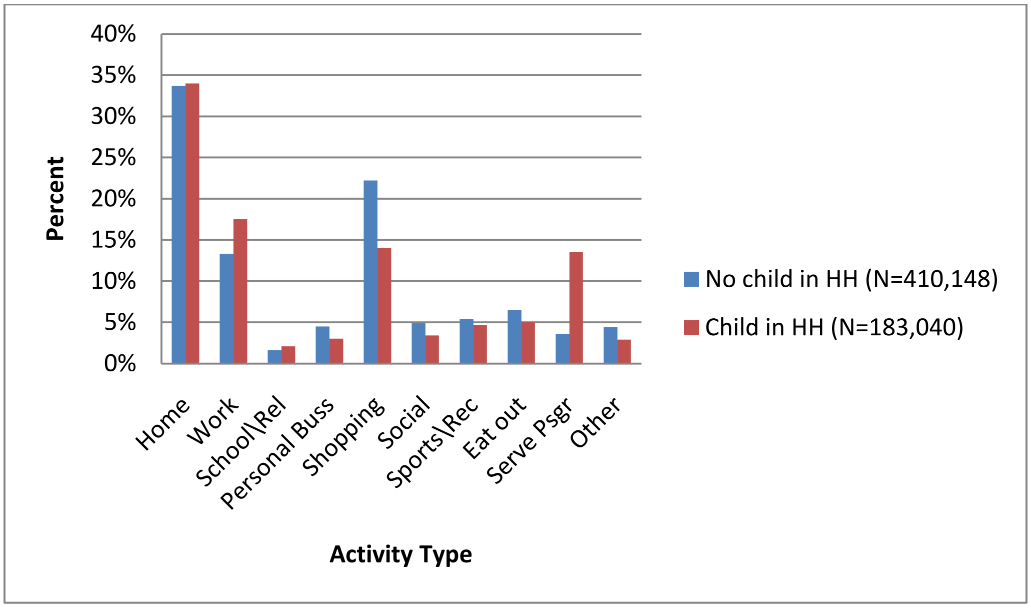

Fig. 4 Activity Type Distributions

The proportion of trips made by adults in households with children for personal business, shopping, social, sports/recreational and eat out activities are less than those of adults in households without children. This is consistent with the patterns found by comparing trip purpose distributions among the adults in these two groups of households (Figure 3). With constraints imposed by the presence of children, it is likely that the adults are able to make a lesser proportion of trips to pursue these kinds of activities. The proportions of trips made by adults in both groups of households to pursue in-home activities are almost the same. At the same time, the share of server passenger trips made by adults in households with children is a lot higher than that of adults in the other category of households. This leads to the conclusion that the presence of children does not necessarily mean less out of home trips and/or activities but children can certainly influence the nature of the trip/activities being pursued by the adults in the household. However, it should be noted that this does not indicate anything about the time being spent in each of these activities and also the time spent traveling which would be analyzed later in this report.

Figure 5 shows the mode splits of the trips made by adults in both kinds of households.

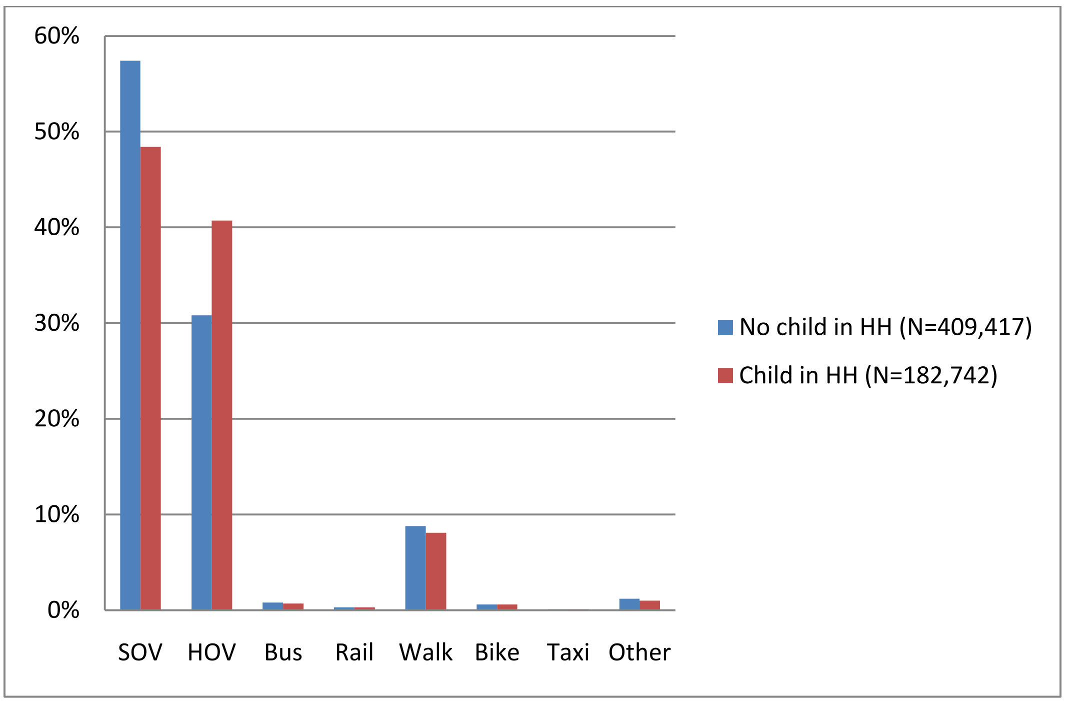

Fig. 5 Trip Mode Shares

Difference in mode shares can be seen mainly in the single occupancy vehicle (SOV) and high occupancy vehicle (HOV) trips. Proportions of the trips made using other modes are almost equal in both the categories. The fact that adults in households with children make a significantly higher share of HOV trips than the adults in households without children indicates the extent of the pick-up/drop-off or joint trip engagement dependencies imposed by the presence of children which may not have taken place otherwise. Table 2 shows the mean lengths and durations of the trips made by adults in both groups of households by activity purpose type.

Table 2 Mean Trip Lengths and Durations by Purpose

	Trip Length (miles)				Trip Duration (minutes)			
	No child in HH		Child in HH		No child in HH		Child in HH	
	N	Mean	N	Mean	N	Mean	N	Mean
Home	136,223	8.5	61,109	8.5	137,541	19.6	62,108	18.6
Work	53,749	11.5	31,452	12.8	54,302	22.6	31,927	23.8
School/ Religious	6,235	8.1	3,751	8.2	6,349	18.7	3,860	18.4
Personal Business	18,109	7.2	5,310	7.2	18,403	18.1	5,424	17.8
Shopping	89,774	5.7	25,148	5.8	90,737	14.0	25,607	13.6
Social	19,678	10.8	5,994	9.8	20,147	23.9	6,181	22.0
Sports/ Recreation	21,845	5.5	8,495	5.6	22,104	19.7	8,611	18.6
Eat out	26,109	6.2	8,950	5.7	26,436	15.1	9,052	13.3
Serve Passenger	14,349	9.3	24,345	6.1	14,613	18.9	24,689	13.5
Other	17,472	12.5	4,916	12.9	18,149	28.4	5,238	30.4
All	403,543	8.2	179,470	8.4	408,781	19.0	182,697	18.3

The average trip lengths of adults in households with and without children are 8.4 and 8.2 miles respectively which are almost the same. Similarly, average trip durations are similar to each other (18.3 and 19 minutes). A closer examination of the distributions by activity purpose shows some subtle variations. On average, adults in households with children travel farther and longer for working than the other group of adults. This might indicate that there are other considerations such as distance to school and child care centers that might go into choosing the commute distance and time for adults living in households with children. In case of other non-mandatory activities, it is conceivable that adults in households with children would want to travel less and for shorter durations than the other set of adults due to two reasons. First, if a child is not traveling with the adults and is not fully dependent then they would have to return home sooner. Second, in case a child is traveling with the adults, it may not be very comfortable for the child to travel father distances and for longer durations. This is exactly what has been observed. Adults in households with children spend less time traveling to sports and recreational activities than their counterparts in households without children. A more significant difference can be seen in the travel to eat out activities. Adults in households with children go to destinations which are closer and spend less time reaching them than adults in households without children. Even for the serve passenger trips, these adults choose destinations which are relatively nearer and spend much less time traveling to them which might be due to the presence of children on these trips. It should be mentioned again here that all this is no indication of the amount of time spent by these adults in all these activities.

Figure 6 shows time of day distributions of the trips made by adults in both kinds of households. It is clear that adults in households with children are making a relatively higher proportion of trips in the peak periods than adults in households without children. This suggests that these adults are required to cater to the travel needs of children such as pick-up/drop-off to school and/or before/after school activities in these periods of the day.

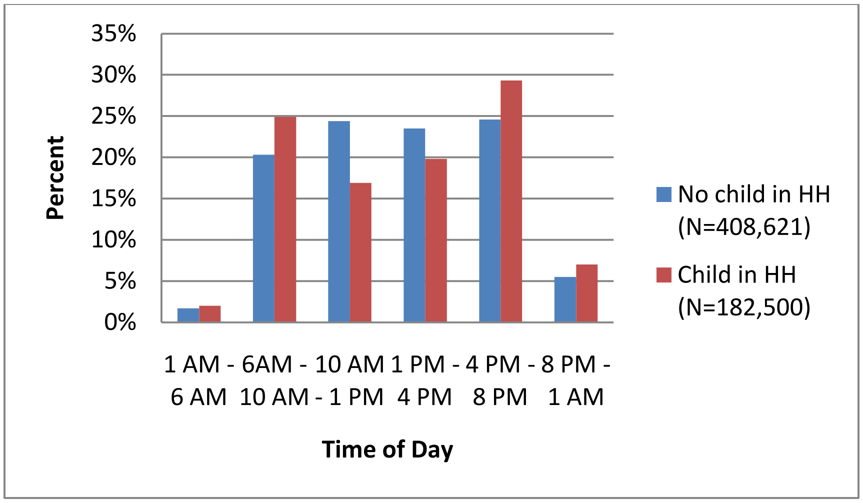

Fig. 6 Time of Day Distributions

It would also be interesting to compare the activity engagement frequencies and time-use patterns of the adults residing in household with and without children. Table 3 and Table 4 show such a comparison of the patterns on a typical weekday (Monday through Thursday). On average, adults in households with children engage in more number of travel episodes than adults in household without children. Their daily travel expenditure is higher and a higher percentage of them are mobile on a given travel day. They also engage in considerably more work, school, and serve passenger episodes both in terms of frequency and duration. A significantly higher proportion of adults in households with children engage in serve passenger activities when compared to that of adults in households without children (30% as opposed to only 7.1%) on a typical weekday. This supports one of the motives of this study to link the dependencies that might be associated with children to the adults' activity-travel schedules.

Table 3 Average Activity Episode Frequencies and Durations

Activity Type	Adults in HH without Children (N= 110,470)			Adults in HH with Children (N= 40,338)		
	Avg No of Episodes	Avg Daily Time Exp	Avg Daily Time Exp (non-zero only)	Avg No of Episodes	Avg Daily Time Exp	Avg Daily Time Exp (non-zero only)
At Home	3.09	1123.05	1123.05 (100.0%)	3.45	1014.15	1014.15 (100.0%)
Work	0.49	146.24	460.83 (31.7%)	0.79	246.42	472.39 (52.2%)
School/Religious	0.06	8.33	167.38 (5.0%)	0.10	13.87	176.97 (7.8%)
Personal business	0.17	9.02	76.07 (11.9%)	0.13	7.02	72.35 (9.7%)
Shopping	0.82	22.97	53.33 (43.1%)	0.64	18.45	49.83 (37.0%)
Social Visits	0.18	18.74	140.69 (13.3%)	0.15	14.59	131.33 (11.1%)
Recreation/Sports	0.20	14.25	98.19 (14.5%)	0.21	14.56	91.34 (15.9%)
Eat Out	0.24	11.57	56.73 (20.4%)	0.22	8.71	46.03 (18.9%)
Serve Passenger	0.13	2.99	42.18 (7.1%)	0.61	9.31	30.88 (30.1%)
Other	0.17	11.5	91.57 (12.6%)	0.13	9.21	96.92 (9.5%)
Travel	3.71	71.33	85.5 (83.4%)	4.54	83.74	92.32 (90.7%)

Table 4 Average Travel Episode Frequencies and Durations

Travel Purpose	Adults in HH without Children (N= 110,470)			Adults in HH with Children (N= 40,338)		
	Avg No of Episodes	Avg Daily Time Exp	Avg Daily Time Exp (non-zero only)	Avg No of Episodes	Avg Daily Time Exp	Avg Daily Time Exp (non-zero only)
Return Home	1.25	24.63	30.78 (80.0%)	1.54	28.79	33.00 (87.2%)
Work	0.49	11.31	34.8 (32.5%)	0.79	19.12	35.68 (53.6%)
School/Religious	0.06	1.09	21.72 (5.0%)	0.10	1.76	21.94 (8.0%)
Personal business	0.17	3.08	24.16 (12.7%)	0.13	2.42	22.87 (10.6%)
Shopping	0.82	11.55	26.16 (44.1%)	0.64	8.61	22.73 (37.9%)
Social Visits	0.18	4.66	32.36 (14.4%)	0.15	3.50	28.80 (12.2%)
Recreation/Sports	0.20	3.98	24.04 (16.5%)	0.21	4.01	22.39 (17.9%)
Eat Out	0.24	3.63	17.45 (20.8%)	0.22	3.01	15.55 (19.3%)
Serve Passenger	0.13	2.51	32.37 (7.8%)	0.61	8.34	25.10 (33.2%)
Other	0.17	4.91	36.81 (13.3%)	0.13	4.20	40.84 (10.3%)

On the other hand, adults in households with children are engaging in personal business, shopping, social visits, and eat out activities less frequently and for shorter durations when compared to adults in households without children. It may be possible that on a typical weekday, adults in households with children are minimizing their frequencies and durations with respect to these activities since they are more non-mandatory in nature and also due to the fact they are engaging in more mandatory (work/school) activities which gives them less time to pursue other types of activities. It is also interesting to note that though these adults have a higher frequency of in-home activity episodes, the daily time expenditure on in-home activities is less when compared to adults in households without children. This combined with the fact that the number of travel episodes is higher could potentially indicate that there are a significant percentage of pure serve passenger trips which would require adults in households with children to return home more frequently but stay only long enough before it is time for the next serve passenger activity.

Table 4 analyzes the travel episodes in greater detail. It is apparent that the adults in households with children return home more frequently and spend longer time traveling. Again travel for shopping, personal business, social visits, and eat out activities is significantly less frequent and shorter in duration for these adults. However, travel frequencies and durations for other mandatory kinds of activities such as work, school, and server passenger activities more than make up for loss in travel for non-mandatory activities and result in net higher travel frequency and time expenditure for adults in households with children. This is important because if it were the case that adults in these two groups of households differed mainly in their activity engagement patterns and not so much in their travel patterns, modeling of their special constraints and dependencies would have been relatively less critical.

3.4. Tour-Based Comparison

This section analyzes in detail how the activity-travel patterns of adults in households with and without children differ in terms of their tour and trip chaining characteristics. Table 5 shows a comparison of the tour types and complexities associated with them.

Table 5 Tour Type Distributions

Tour Type	Adults in HH without Children (N= 110,470)		Adults in HH with Children (N= 40,338)	
	Avg Freq	% of Adults	Avg Freq	% of Adults
Simple HBW	0.19	18.2%	0.28	26.2%
Complex HBW	0.11	10.7%	0.23	22.0%
- To Work only	0.02	2.4%	0.06	6.2%
- From Work only	0.07	6.6%	0.10	9.5%
- Both directions	0.02	1.8%	0.07	6.7%
Simple HBO	0.57	40.1%	0.68	44.0%
Complex HBO	0.35	31.1%	0.33	27.2%
- 2 stops	0.16	15.2%	0.17	15.5%
- 3 stops	0.09	8.8%	0.08	7.8%
- 4 or more stops	0.09	9.2%	0.07	7.0%
Work Based	0.07	6.0%	0.11	9.7%
- 1 stop	0.06	5.0%	0.10	8.3%
- 2 stops	0.01	0.8%	0.01	1.1%
- 3 or more stops	0.00	0.4%	0.01	0.6%
TOTAL	1.30	79.0%	1.63	86.0%

At first glance, it appears that the adults in households with children are engaging in a higher number of tours on an average weekday. There is a significant difference especially in simple and complex home-based work and simple home-based other tours. These adults have higher frequencies of all of the subcategories of complex home-based work tours – stops made to work only, from work only and in both directions. This is where most of the child dependency linkages may need to be recognized and considered in the overall model framework. On the other hand, adults in households with children pursue less number of other complex home-based tours. This may be attributed to the fact that some of these may involve children and pursuing complex tours with children may be relatively more onerous. Since a pure serve passenger tour would also be of the type simple home-based other, the higher frequencies and proportions of adults in households with children being associated with this type of tours is not unexpected.

Table 6 shows a comparison of the tour mode splits observed for the adults in the two sets of households. Adults in households with children pursue a significantly lower proportion of tours on SOV only mode (which means an SOV throughout the tour). On the other hand, they pursue a significantly higher share of tours on SOV+HOV mode which means the tour was completed partly on an SOV and partly on an HOV. This observation indicates a considerable magnitude of pick-up and drop-off trips or half-tours which may be attributed to the presence of children in the household especially in case of complex home-based work trips.

Table 6 Tour Mode Distributions

Tour Type	Adults in HH without Children	Adults in HH with Children
Simple HBW	N=21372	N=11123
SOV only	62.2%	48.1%
HOV only	4.6%	6.1%
SOV+HOV	11.0%	21.6%
Bus	0.6%	0.7%
Rail	0.3%	0.4%
Walk	1.2%	0.8%
Bike	0.3%	0.4%
Multimodal	18.9%	21.1%
Complex HBW	N=11994	N=9071
SOV only	55.5%	21.7%
HOV only	3.8%	4.5%
SOV+HOV	11.7%	33.1%
Bus	0.1%	0.1%
Rail	0.0%	0.0%
Walk	0.3%	0.2%
Bike	0.1%	0.0%
Multimodal	28.1%	40.1%
Simple HBO	N=63441	N=27479
SOV only	29.1%	10.1%
HOV only	14.6%	13.3%
SOV+HOV	18.3%	25.8%
Bus	0.4%	0.3%
Rail	0.0%	0.0%
Walk	4.5%	3.1%
Bike	0.3%	0.2%
Multimodal	32.1%	46.8%
Complex HBO	N=38375	N=13225
SOV only	32.0%	9.5%
HOV only	23.0%	21.1%
SOV+HOV	16.8%	26.0%
Bus	0.2%	0.2%
Rail	0.0%	0.0%
Walk	0.7%	0.6%
Bike	0.1%	0.1%
Multimodal	26.9%	42.4%

Even in the case of complex-home based other tours, adults in households with children make a higher share of tours on mixed SOV and HOV modes indicating the presence of pick-up/drop-off activities for child related activity-travel needs. Table 7 presents a comparison of the distributions of tour accompaniment types.

Table 7 Tour Accompaniment Distributions

Tour Type	Adults in HH without Children	Adults in HH with Children
Simple HBW	N=21407	N=11137
Purely joint	6.0%	7.7%
Purely solo	91.2%	87.1%
Partly solo and joint	2.3%	3.7%
Varying joint	0.6%	1.5%
Complex HBW	N=12013	N=9078
Purely joint	4.0%	2.6%
Purely solo	79.9%	38.0%
Partly solo and joint	15.1%	55.7%
Varying joint	1.0%	3.7%
Simple HBO	N=63497	N=27510
Purely joint	26.9%	28.7%
Purely solo	66.9%	43.1%
Partly solo and joint	4.7%	20.9%
Varying joint	1.6%	7.3%
Complex HBO	N=38429	N=13241
Purely joint	29.5%	25.8%
Purely solo	50.4%	24.6%
Partly solo and joint	15.7%	34.2%
Varying joint	4.4%	15.4%
Work Based	N=7931	N=4622
Purely joint	15.4%	17.3%
Purely solo	80.4%	77.4%
Partly solo and joint	3.2%	4.5%
Varying joint	1.0%	0.9%

For complex home-based work trips, the proportion of partly solo and joint tours made by adults in households with children is significantly higher than that of adults in households without children and at the same time, the percentage of purely solo tours is significantly lower. This indicates the possibility of the pick-up and/or drop-off activities being accomplished more during the commute between home and work than during other types of tours. The same pattern can also be observed in case of other complex home-based tours and can be attributed again to the serve passenger dependencies due to the presence of children. It can also be noted that the difference in the proportions of partly solo and joint tours in case of simple home-based other tours is much higher than in case of simple home-based work tours. This again may be due to the pure pick-up and drop-off travel that may need to be made by adults to cater to the activity-travel requirements of children in the household.

3.5. Joint Trip Characteristics

This section explores the nature of joint trip making characteristics of children, particularly those in age group 5 through 17 years as those less than 5 years of age may be assumed as always making joint trips only. As mentioned earlier, 2001 NHTS dataset is used for this analysis since the 2009 dataset does not have information about accompanying persons on the trip in the public use files. This analysis aids in the design of the framework for child dependency models that are developed and presented later in the thesis.

Table 8 shows the distribution of joint travel arrangement types of children between 5 and 17 years of age by various activity types. It can be seen that the percentage of solo trips is relatively very high (61%) for pursuing work related activities only. In NHTS, non adults eligible to work have a minimum age of 16 years. For all of the other activity types, the proportions of joint travel arrangements clearly dominate ranging between 80% and 90%. This indicates a significantly high dependence of children between 5 and 17 years old on adults for their activity-travel needs.

Table 8 Joint Travel Arrangement by Activity Type

	Joint Travel Arrangement					
Activity Type	Solo	HH Adults Only	HH Adults and Children	HH Children Only	HH and Non-HH	Non HH Only
Home (N=35,691)	22.8%	21.9%	29.6%	7.0%	8.9%	9.8%
Work (N=1,119)	61.2%	22.1%	3.0%	1.6%	1.9%	10.2%
School\Rel (N=18,795)	27.0%	18.2%	22.0%	12.3%	9.0%	11.6%
Pers. Buss. (N=2,186)	15.5%	29.1%	33.9%	2.1%	10.1%	9.3%
Shopping (N=11,185)	7.2%	30.7%	43.3%	1.7%	10.7%	6.5%
Social (N=8,751)	22.5%	16.0%	27.3%	3.9%	12.0%	18.2%
Sports\Rec (N=7,392)	17.5%	19.9%	26.0%	4.8%	13.4%	18.3%
Eat out (N=4,347)	6.5%	22.6%	39.7%	1.7%	15.5%	14.0%
Serve Psgr (N=4,900)	6.8%	23.5%	35.8%	3.8%	21.9%	8.3%
Other (N=2,338)	15.7%	25.3%	33.1%	3.8%	11.3%	10.7%
Total (N=96,704)	19.9%	21.9%	29.9%	6.3%	10.7%	11.3%

On the other hand, lowest proportions of individual travel among children are observed for shopping, eat out and serve passenger activity types. This is reasonable considering that children may have a lesser tendency and need to shop, get meals by themselves, and drop-off/pick-up other members of the household. Among all of the joint travel arrangement types, the percentage of travel involving both household adults and children is considerably higher than the other types (except in the case of travel to work). This may indicate that when one household child is involved in a joint trip, there is a high tendency for one or more of the other household children (if present) also to be involved in the trip. In case of work, it is quite likely that the child can travel independently and therefore would not require an adult to accompany him or her on the travel episode. Another observation which is quite intuitive is that the lowest proportions of all joint travel types are those involving only children. There seems to be a very significant amount of joint travel involving non-household members which is ranging from 12% (work) to as high as 30% (social visits, sports/recreation and eat out activities). This is consistent with some of the observations made in previous studies (e.g., Yarlagadda and Srinivasan 2008). Modeling of such joint travel episodes is quite complex and involves theories of social networks and inter-household interactions. In addition, it would also add considerable burden to the data collection effort. In this study, the framework developed is envisioned to take into account joint travel involving household adults only and also both household adults and children.

4. MODEL FRAMEWORK

The descriptive analysis in the previous chapter shows that there could be a wide range of interdependencies resulting in significantly different activity-travel patterns for adults in households with children when compared to those in households without children. These dependencies when not accounted for might render an activity-based microsimulation model insensitive to policies affecting intra-household adult-child interactions such as Safe Routes to School (SRS) and even those that affect the adults' mode choice to work (Vovsha and Petersen 2005). This provides a sound motivation for the development a framework for modeling child dependency linkages to adult daily activity-travel patterns. The current chapter presents one such framework for generating the activity-travel needs of children between ages 0 and 17 years. As mentioned earlier, this framework needs to be employed before the generation of activity-travel patterns of adults in a household with children. The child dependencies generated from this framework impose additional constraints on household adults with respect to the generation of their other non-mandatory/discretionary activities can further be generated.

Figure 7 shows the dependency model framework for pre-school children who are between 0 and 4 years age. A reasonable assumption which is made here is that children in this age group do not have their own activities to engage in and they are just under the care of one of the adult household members at home. When all adult household members are out-of-home working or pursuing other activities, these children need to attend pre-school or just accompany one of the adults on his or her travel itinerary. On a given travel day, it first needs to be predicted whether or not a child attends pre-school. In this framework, the model is a rate-based probability one. If it is found that the child needs to attend pre-school, a pick-up and a drop-off event are assigned to the household. It is important to note that these dependency activities are being assigned to the household as a whole and not a particular adult household member at this juncture. There are a couple of reasons for this. One is to take into account other such dependency events generated with respect to the remaining children in the household. The other reasonis to allow for the household adult daily mandatory activities (e.g., work) to be simulated first; that would then allow one to assign an adult for a particular dependent activity in a feasible manner.

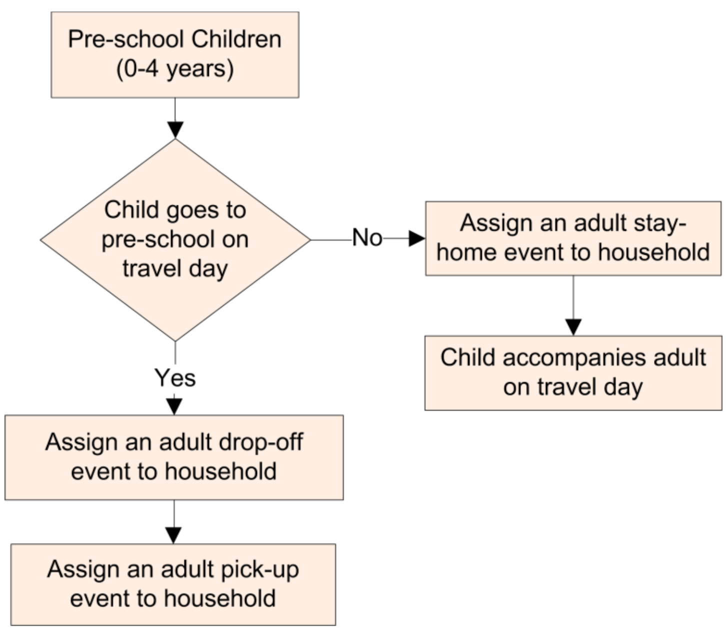

Fig. 7 Pre-school Children Dependency Framework

If it is predicted that a child does not attend pre-school on the travel day, an adult stay-home event is assigned to the household which would mandate one of the adult household members to stay home and take care of the child. It does not however restrain the adult from pursuing other out of home activities as long as the person is able to take the child/children along. In this way joint travel and activities in the household are generated in an intrinsically consistent manner.

The generation of dependencies for the other category of school going children between 5 and 17 years of age certainly involves more complexities. This is mainly because going to school broadens the range of activities that they can pursue. Moreover, the children are also old enough to pursue some activities on their own. Therefore, more dependencies would have to be generated for this set of children than just drop-off to and pick-up from school. Figure 8 shows the dependency framework for school going children between 5 and 17 years.

As in the case of pre-school children, the first process that needs to be simulated is the decision to go to school on the travel day. This can again be a simple probability-based model. It is believed that modeling this explicitly as a choice is not required. An event of a child not going to school may occur randomly with a certain probability such as the child falling sick. This decision would require different dependencies to be linked based on whether or not the child can independently engage in activities, including those inside home.

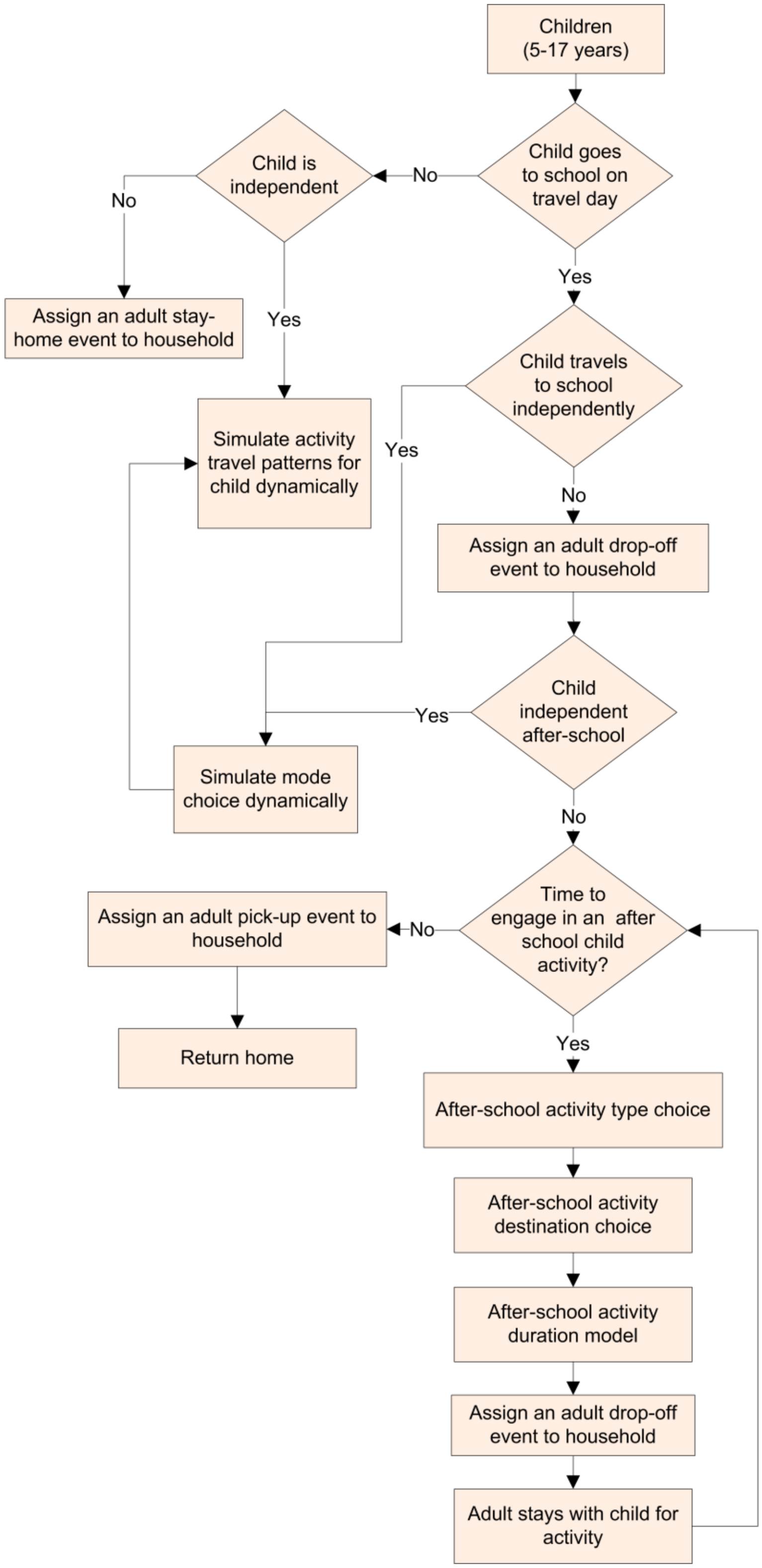

Fig. 8 School Children Dependency Framework

If it is predicted that the child does not attend school, a determination is made as to whether he or she is independent in terms of staying at home and pursuing non-school related activities. This decision is modeled as a discrete outcome (binary) with characteristics of both the child and the household. Though there might be some attitudinal and perception variables pertaining to the parents of the household that may be influencing this outcome, they are not incorporated in the current design, due to data limitations.

If the child is not independent, it is quite likely that there needs to be an adult at home to take care of the child. This adult is assigned the care of the child for the rest of the day unless another household adult is assigned this child for a different activity later. Hence, the model generates a household adult “stay-home” event similar to that generated in the case of pre-school children. This outcome is predicted for every child in the household so that in a subsequent model, there can be a determination of the specific adult(s) assigned to take care of all the dependent children at home on the travel day being simulated. On the other hand, if it is predicted that the child is independent, then the child is treated as an adult for the purposes of the model. Activities are simulated for an independent child just as they would be for an adult in the subsequent activity-travel generation models. It should be noted here that set of models presented in this thesis is specifically for the purpose of linking dependencies due to the presence of children in the household and incorporating those interactions in the activity-based microsimulation framework and not for the generation of full-fledged daily activity-travel patterns.

The next set of outcomes determines whether or not a child is independent in terms of travel to school and also to after school activity locations. Both these decisions can again be modeled as binary discrete outcomes as in the case of the previous child activity independence model. If a child is capable of independent travel to and after school, mode choice can then be simulated in subsequent models. This is not particularly relevant to the objective of this effort which is to create child dependency linkages. It is only when the child is not independent that other linkages need to be tied in. Based on outcomes of the previous models, drop-off and/or pick-up events are assigned to the household as a whole (as noted in the recommendations by Vovsha and Petersen 2005). This would subsequently entail the assignment of chauffeuring duties to household adult(s). Again if more than one child require chauffeuring, it is more likely that a single household adult would be assigned with the task of dropping them off and/or picking them up from school.

Once the drop-off to and pick-up from school are assigned, the focus then shifts to after school activities of dependent children ages 5 through 17 years such as playing soccer or attending a music class and tying them up with a household adult if chauffeuring is required. This effort focuses on all non-mandatory activities only after school because close to 90% of children do not pursue these activities before school and almost the same percentage of children pursue these kinds of activities after school. Even the adults in the household have a higher probability to escort and/or participate in activities with children after school than before due to their other work/mandatory activity engagements. It is likely that adults who are employed tend to engage in ride-sharing with children before school. However, after school, they could spend more time pursuing non-mandatory/discretionary joint activities with children either directly from school after a pick-up or after returning home first.

The task to differentiate between activities "for" children as opposed to activities just "involving" children using a travel survey dataset is not a trivial one. Due to this reason all activities which involve joint travel with children are considered for modeling the dependencies associated with after school activities. It can be argued that this may tend to overestimate the child chauffeuring or escorting activities. However, it is still joint travel involving children. Even though a trip was not made for the child, it still involved the child. It might also be possible that travel was being undertaken to pursue an activity for the sake of both the adult and the child or the whole household itself (grocery shopping for example). In most of the cases, these activities would essentially constrain or lock-up the schedules of one or more adults of a household during a particular day. Again, it is being assumed here as it has been numerous times in previous literature that joint activity-travel is considered higher in the model system hierarchy than individual travel. In other words, joint activity-travel engagements take precedence over individual ones.

The decision to generate after school activities is based on the time remaining in the open prism of the child before he or she needs to get back home. If it is determined that a child has enough time available to pursue after-school activities, a set of models is used to simulate the activity-travel dimensions. First, a Multinomial Logit (MNL) model of activity type choice is used to predict the after school activity type. Another MNL model is needed to predict the destination location of the activity. Finally the activity duration is modeled as a log-linear regression model. It is also determined at this stage whether or not a household adult is required to stay or just decides to stay and engage in the activity jointly with the child. If the adult stays, then both the travel episode and activity episode are locked in the chosen adult's daily activity schedule; if not, only the travel episode gets blocked after which other non-mandatory activities can be generated and simulated for the adult. If there is more available time for the pursuit of non-mandatory activities by the child without violating his or her space-time prism constraints, the set of three models of activity type, destination and duration is run in sequence again to further constrain the daily activity schedule of one of the adults in the household. This process repeats until there is no more time left to pursue activities without violating the prism constraints and at which point a household adult would be required to just chauffeur the child back home. It is very important to note that at any point in time, the child may choose to pursue an in-home non-mandatory activity or just return home instead of pursuing further out-of-home activities requiring joint travel and activity engagement with a household adult. In other words, there is a “return home” or “in-home” activity type in the choice set. It is also important to mention that each time an after school activity is generated, a drop-off/pick-up event is assigned to the household and the specific adult who would be involved in escorting/chauffeuring can be determined subsequently using either heuristics or a choice model.

5. MODEL ESTIMATION RESULTS

This chapter presents the estimation results of models that represent various decision and choice processes in the child dependency framework.

5.1. Daily School/Pre-school Attendance Model

For both pre-school and school children, it is proposed in the framework that simple rate-based probability models be used and that explicit modeling of attendance as a choice process is not required. For estimating the probability of children 0 to 4 years old attending pre-school, 2001 NHTS is used since trip information for pre-school children was not collected in the latest 2009NHTS There were 5,810 pre-school children in the 2001 NHTS sample of persons whose assigned travel day was between Monday and Thursday. If it is found that a child made at least one trip for school or day-care purposes, the child is considered to have attended pre-school on that particular day. Table 9 shows the daily pre-school attendance rates by age.

Table 9 Pre-school Attendance Rates

Age (years)	Frequency	Attendance Frequency	Probability
0	1049	162	0.15
1	1035	185	0.18
2	1294	314	0.24
3	1204	375	0.31
4	1228	507	0.41
Total	5810	1543	0.27

An intuitive trend observed is that the probability of a child attending pre-school on a travel day is continuously increasing with age. It appears reasonable that the proportion of younger children attending pre-school on a typical weekday is lower than that of older children. These probabilities can be used to simulate whether or not a child attends pre-school on a particular travel day. Similar age-based probabilities generated for school children during weekdays Monday through Thursday are shown in Table 10.

Table 10 School Attendance Rates

Age (years)	Frequency	Attendance Frequency	Probability
5 - 10	11188	7519	0.67
11 - 14	8257	5549	0.67
15 - 17	6369	4169	0.65
Total	25814	17237	0.67

As it can be expected, school attendance rates are much higher than pre-school attendance rates. The main difference is that the probability of a child attending school is not varying much with age of the child. This may be due to the fact that all school age children attend school and it is not exactly at the discretion of parents as in the case of pre-school attendance.

5.2. Child Dependence Model

The child dependence model represents dependent status of the child with respect to three components in the model framework 1) at home 2) during travel to school, and 3) after school. This simplifying assumption is made to estimate the model on a larger sample and obtain a richer specification. Another reason for the assumption is to achieve some amount of behavioral consistency since it is quite probable that a child who can travel independently to school may also be independent enough to return home from school and stay at home alone without adult supervision. Under this assumption, children who are found to be accompanied by an adult in all of the three cases are assigned a dependent status and all others are considered independent. Table 11 shows the estimation results from a binary probit model for child dependence. All of the variables are significant within the 5% level.

Table 11 Child Dependence Model

Variable	Coeff	t-stat
Constant	-0.932	-21.6
Child Characteristics		
Age between 5 and 10 years	0.728	29.9
Age between 11 and 14 years	0.345	13.8
Male	-0.088	-5.4
Race is Hispanic	0.297	9.7
HH Characteristics		
HH income less than 35k per year	-0.075	-3.5
HH in urban area	0.037	2.0
Number of unemployed persons	0.031	4.8
Number of drivers	0.035	3.0
Number of children	0.002	2.6
Number of observations	25188	
Log likelihood	-15888.48	
Restricted log likelihood	-16618.63	
Chi squared	1460.30	
Estrella	0.06	
AIC	1.26	

Independent child is considered as the base outcome and the coefficients estimated are with respect to that. The negative constant indicates that in general, children are independent. This is intuitive considering that children between 5 and 17 years old are not totally dependent on adults for all their activities and are probably independent in at least one of the three dependence cases. Age is a dominant explanatory variable among child characteristics. Both the age category indicator variable coefficients being positive imply that children in these categories tend to be more dependent on adults than children whose age is greater than or equal to 15 years which is reasonable considering that older teenagers are likely to be more independent. Also, a comparison of the magnitudes of coefficients of the age category indicator variables shows that children in the younger age category (between 5 and 10 years) tend to be more dependent than those in the older age category (between 11 and 14 years) which is again very intuitive. The negative coefficient of a male indicates that boys tend to be more independent than girls which can be attributed to traditional gender differences. Also, there were a few interaction variables between gender and age that were introduced in the model specification but they turned out to be insignificant. Hispanic children are more likely to be dependent on adults than children belonging to other races which may be due to cultural differences.

Moving on to household level explanatory variables, it can be observed that children in households with low income (less than $35,000 per year) tend to be more independent than children in households with higher incomes. This shows that child dependence may to some degree be associated with household income. There are two possible interpretations for this – either the children themselves are more used to adult accompaniment since young age and thus are less independent or the adults in such household tend to be more protective of children and are more likely to accompany them on their trips. Children living in households in urban areas have a higher probability of being dependent. Again, this might be a result of the adults in these households being more cautious. Urban areas are generally associated with higher traffic volumes and crime rates when compared to rural areas. These kinds of safety concerns might be influencing the adults in not letting children engage in travel and/or activities on their own. Both the number of drivers and unemployed persons in the household influence the probability of a child being dependent positively. This may be more a result of opportunity than anything else. Both these variables quantify the number of persons available to chauffeur and make serve passenger trips in the household. Again, this means that even if the child is capable of traveling independently, just because there are people in the household who can drive/accompany the child on his or her trip, an adult tends to travel with the child. Number of children in the household too increases the likelihood of dependence of the child under consideration. A plausible explanation for this could be based on convenience. If a household adult is picking-up/dropping-off one household child at an activity location, he or she may as well serve another child in this process. This phenomenon is especially relevant in travel to and from school since all the children in the household are likely to attend the same school.

As mentioned earlier, though there might be some other attitudinal and perception related variables pertaining to the adults of the household that may be influencing this outcome, they are not incorporated in the current design. The main reason for this is to ensure the use of the models for microsimulation purposes. Since activity-based microsimulation models are generally run on a synthetically generated population, all kinds of variables may not be available. Therefore a decision/choice outcome in most of the models in the proposed framework is modeled using socio-demographic variables and their combinations.

5.3. Activity Type Choice Model

The activity type choice model is used to generate non-mandatory activities for dependent children after school and before returning home. It is important to note that the travel for all these activities is required to be joint in nature since these activities pertain to children who are simulated as not being independent in terms of travel. Therefore, only those trips made with one or more adult household members are filtered out for model estimation purposes. The activity type choice is then obtained from the detailed trip purpose. There are very disaggregate types of activities considered – home, work, personal business, shopping, social visits, sports and recreation, eat out, serve passenger, and other. Work and serve passenger are also considered as potential activity types since children between 5 and 17 years include individuals of working and driving age who are capable of pursuing both these types of activities. Estimation attempts incorporating variables choice sets for these children resulted in model non-convergence issues. Hence, a universal choice set consisting of all the nine categories is designated for each child. Table 12 shows the estimation results of a Multinomial Logit (MNL) model with activity type 'other' considered as the base alternative.

Table 12 Activity Type Choice Model

	Home		Work		Personal Business		Shopping	
Variable	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Constant	2.073	8.2	-4.494	-5.5	-1.401	-4.3	0.793	5.1
Activity Characteristics								
Time spent in-home (mins)	-0.003	-9.2						
Time spent in social/rec/sports (mins)							-0.004	-3.4
Time spent in shopping/pers buss/meals (mins)								
Time spent at school/work (mins)								
Time of Day Variables								
Between 6AM and 9 AM	-1.570	-4.2						
Between 12PM and 3PM	2.073	8.0			0.990	2.0	1.337	5.7
Between 3PM and 5PM	2.042	9.6			0.978	2.4	0.783	4.2
Between 5PM and 7 PM	2.542	9.7			1.868	4.3	1.441	5.9
After 7 PM	3.692	13.1			1.987	4.2	1.521	5.5
Socio-Demographic Characteristics								
Age 15 years and over			3.741	4.8				
HH annual income less than 35k			1.434	2.4				
Number of observations	2365							
Log likelihood	-3525.619							
Log likelihood (constants only)	-3889.1886							
R-sqrd	0.0935							
Adjusted R-sqrd	0.0913							

Table 12 continued

Variable	Social Visit Coeff	t-stat	Sports Rec Coeff	t-stat	Eat out Coeff	t-stat	Serve Passenger Coeff	t-stat
Constant	-1.255	-3.9	-0.588	-2.5	0.341	0.9	0.467	1.9
Activity Characteristics								
Time spent in-home (mins)	0.001	3.2			-0.002	-3.4		
Time spent in social/rec/sports (mins)	0.002	2.6	-0.003	-1.7				
Time spent in shopping/pers buss/meals (mins)	-0.007	-2.7						
Time spent at school/work (mins)							0.001	2.6
Time of Day Variables								
Between 6AM and 9 AM								
Between 12PM and 3PM	0.749	2.4	0.937	2.4	1.394	3.9		
Between 3PM and 5PM			1.122	3.9				
Between 5PM and 7 PM	1.444	5.1	2.627	8.6	2.075	6.6		
After 7 PM	1.300	3.6			2.973	8.7		
Socio-Demographic Characteristics								
Age 15 years and over							0.400	2.0
HH annual income less than 35k	0.623	3.6	-0.552	-2.6	-0.616	-2.5		
HH in urban area							-0.542	-3.1
Number of children in HH							0.212	3.5

From the constants alone, it can be seen that children have a high probability of just returning home from school and pursuing in-home activities. All other things being equal, they are least likely to work which is an intuitive result. They are more likely to engage in shopping followed by serve passenger, eat out, sports/recreation, social visits, and personal business activity types in the decreasing order of likelihood. A few activities may be those of adults, but as noted earlier, the task to isolate those is not trivial. It can also be observed that the choice process of activity type is more influenced by time of day and history related activity engagement pattern variables than socio-demographic variables. The time spent prior to the current choice of activity type during a particular travel day is broadly divided into times spent in home, fixed, maintenance and discretionary activities. Fixed activities consist of work and school episodes, maintenance activities include shopping, personal business, and meals whereas social and sports/recreation make up the discretionary activities category. Time spent previously at home influences the choice of an in-home activity negatively. This is intuitive considering that a child who might have already spent some amount of time in home until a decision point would want to go out and pursue other kinds of activities. At the same time, historic engagement in other kinds of activities does not have a significant effect on the choice of pursuing an in-home activity since after a while, a child must return home. Activity history variables were not found to be significant for work and personal business activities. It is possible that for children, these activities are not that frequent. Another reason might be the low sample size for these kinds of activities among children. It is also explored if time spent in one activity category significantly influences the choice of an activity in another category. The choice of shopping is found to be negatively influenced by previous engagement in discretionary activities. This might just be reflecting the time availability constraint due to which time spent in one kind of non-mandatory activity might result in insufficient time being available for another kind of non-mandatory activity and hence the reduced probability of it being chosen. The only exception was found in case of social visits where previous activity engagement influenced the future choice positively. Though it might not appear intuitive at first, it is possible that engagement in a particular social visit leads to further engagement in that type of activity. For example, if a child and adult make a trip to meet a family member or friend, they might also end up meeting some other friends and/or relatives subsequently. Time spent in-home too resulted in a more likely choice of a social visit activity type which may be due to the explanation given earlier for in-home activity time affecting in-home activity type choice negatively. On the other hand, time spent in maintenance activities is found to affect the choice of social visit negatively just for the same reason as discretionary activity engagement influences shopping (maintenance) activity negatively. Previous engagement in discretionary activities negatively influences the choice of sports/recreation activity. There is probably only so much sports/recreation a child can engage in on a given day. Time spent in home is found to decrease the probability of an eat-out activity being pursued.

The reason for this could be that if a child spends more time at home he or she may have taken his or her meal as well. Considerable amount of time spent at work increases the probability of a serve passenger activity. This might be specially related to non-adults who work and might have to share the responsibility of picking-up other children in the household (from their respective after school activities) after their work episode.

All the time of day explanatory variables are both highly significant and intuitive. It is unlikely that a child would choose an in-home activity during the morning period from 6 AM to 9 AM but the likelihood increases considerably during all periods after 12 PM representing the return of children from school or various after school activities. Similarly, the probability of choosing all other non-mandatory activities is relatively high during certain periods in the afternoon and evening. Work and even serve passenger activities may be considered as more mandatory in nature.

Among socio-demographic variables, age of the child being greater than 15 years influences the choice of work and serve passenger activities positively. This is intuitive considering that driving age is 16 years and these older children would need to share some responsibility of such household activities. The chauffeuring responsibilities also increase further with the number of children present in the households which is reflected in the positive coefficient of number of children for serve passenger activities. Similar reasoning may be applied to explain children from low income households (less than $35,000 per year) having a higher probability of choosing a work episode. It is also found that children from low income households tend to choose social visit activities over sports/recreation ones due to their coefficients being positive and negative for the respective activities. In addition, these children are less likely to choose eat out activities possibly due to budget constraints in their households. Children living in households in urban areas have a lesser probability of engaging in serve passenger activities. It is possible that the reason for this is tied up to the activity engagement patterns of children in urban areas when compared to rural areas. Younger children in rural areas might be engaging in more out of home discretionary activities resulting in a higher probability of serve passenger activities for older children.

5.4. Destination Choice Model

The destination choice model is used to assign a location for the activity type simulated for a child. It should be noted that this model would not be employed for home and work activity type choices for which the destination choices are implied. For all other non-mandatory activities such as shopping, sports/recreation etc, this model may be used to simulate a destination zone chosen by a child to pursue the activity. A multinomial logit model is estimated using NHTS 2009 add-on sample for Maricopa County due to the availability of the latitudes and the longitudes of trip origins and destinations. The latitudes and longitudes were geo-coded to traffic analysis zones (TAZs) defined by the local MPO, Maricopa Association of Governments (MAG). For each trip record, nine destination zones were sampled randomly to generate alternatives to the chosen destination zone. This resulted in ten alternatives for each choice in the sample. Sample size concerns led to the estimation of only one model for all the activity types. There were 1,157 trips records left for children between 5 and 17 years after the removal of all the home and work destination trips. Table 13 presents the model estimation results.

Table 13 Destination Choice Model

Variable	Coeff	t-stat
Zonal Characteristics		
Auto travel time (mins)	-0.2290	-14.2
Retail employment	0.0003	3.8
Public employment	0.0004	4.4
Industrial employment	-0.0001	-2.2
Total area (sq miles)	0.0467	6.0
Single family dwelling units	0.0002	3.1
Activity Type Interactions		
Social visit with auto travel time	0.0326	2.3
Eat out with auto travel time	-0.0569	-1.9
Social visit with population in institutions	0.0060	4.2
Socio-Demographic Interactions with Auto Travel Time		
Income less than 35k per year	-0.0357	-1.7
Number of HH vehicles	0.0113	2.3
Number of observations	1157	
Log likelihood	-900.722	
Log likelihood (no coefficients)	-2664.091	
R-sqrd	0.662	
Adjusted R-sqrd	0.662	

The explanatory variables mainly consist of zonal attributes. Socio-demographic variables are introduced through interaction with the zonal variables due to the generic nature of the choice set. Since a single model was estimated for all activity types, interactions between activity type indicator variables and zonal characteristics/travel skims are introduced into the model specification.

As expected, coefficient of the auto travel time is negative indicating that a closer zone is preferred as a destination choice. Socio-demographic interactions suggest that if a child belonged to a low income household (with annual income less than $35,000 per year), the negative influence of the travel time on destination choice would be stronger. This is probably a result of higher travel costs associated with pursuing an activity at a farther location in combination with the more restrictive budget constraints that may exist in low income households. The coefficient of the interaction between number of household vehicles and travel time is found to be positive implying that a higher number of household vehicles may result in a farther destination being chosen. This is intuitive given that a higher availability of vehicles might impose less restrictions on the how long a vehicle could be used for a specific purpose. This is particularly relevant in case of joint/child dependent trips that are currently being modeled.

Other zonal attributes such as retail employment, public employment, single family dwelling units, and total area have positive coefficients. This can be expected since all these are some kind of measures of maintenance (such as shopping and personal business) and discretionary (such as social visits and eat out) activity opportunities and proxies for the attractiveness of a particular destination zone. On the other hand, industrial employment is found to negatively influence the choice of destination zone for non-mandatory activity purposes.

This again is intuitive since the existence of a higher number of industries would tend to make the zone unattractive for recreation and retail businesses.

Under activity type interactions, the coefficient for auto travel time for a social visit purpose is found to be positive. This suggests that children (and accompanying adults) are less averse to traveling for longer durations for a social visit activity. This is reasonable considering that social visits to friends and relatives are not totally discretionary and there exist some obligations due to which they have to be made irrespective of travel time and distance. Similarly, the population in institutional facilities too affects the choice of a destination for social visit purposes positively. This can be explained by the presence of friends and relatives in institutions such as hospitals who may need to be visited. Finally, negative coefficient for the interaction of eat out activity purpose with auto travel time indicates less likelihood of a farther destination being chosen for getting meals. This can be attributed to the discretionary nature of an eat out activity itself. The utility gained in pursuing such an activity is not comparable to the disutility of traveling to a destination which is relatively far off.

5.5. Activity Duration Model

The activity duration model is used to determine the amount of time spent pursuing an activity simulated. A log regression model is estimated using dwell times in 2001 NHTS trip records. Again, only records with atleast one accompanying adult are considered to reflect the dependent nature of the activity. Table 14 shows the estimation results for the duration model.

Table 14 Activity Duration Model

Variable	Coeff	t-stat
Constant	2.78	40.7
Activity Type		
In-home sojourns	-0.66	-11.8
Personal business	1.17	18.0
Shopping	0.37	5.5
Social visits	1.85	33.4
Sports/recreation	1.94	32.4
Eat out	1.00	13.9
Work x worker	2.96	18.4
Time of Day Variables		
Between 6 AM and 9 AM	-0.51	-8.6
Between 12 PM and 3 PM	-0.15	-3.4
Between 3 PM and 5 PM	-0.53	-12.7
Between 5 PM and 7 PM	-0.73	-11.4
After 7 PM	-1.76	-40.6
Socio-Demographics		
Number of children in HH	-0.04	-4.3
HH in urban area	-0.06	-1.5
Number of drivers in HH	0.03	2.1
Activity and Socio-Demographic Interactions		
Annual HH income < 35k x In-home activity	-0.16	-3.8
Annual HH income < 35k x Sports/recreation activity	-0.38	-3.4
HH in urban area x In-home activity	0.25	4.7
HH in urban area x shopping	0.17	2.4
Time of Day and Activity Type Interactions		
Between 3 PM and 5 PM x Social visits	-0.47	-4.3
Between 3 PM and 5 PM x Eat out	-0.43	-2.9
Between 5 PM and 7 PM x In-home activity	-0.69	-10.0
Between 5 PM and 7 PM x Shopping	0.34	3.9
Between 5 PM and 7 PM x Sports/recreation	0.23	2.4
Between 5 PM and 7 PM x Eat out	0.35	3.0
Number of observations	24154	
Residual sum of squares	67434.91	
Standard error of estimate	1.672	
R-sqrd	0.338	
Adjusted R-sqrd	0.338	

Explanatory variables primarily consist of activity type, socio-demographic, and time of day variables. In addition, a few interaction variables are also included in the model specification. Apart from the constant for the whole model there are indicator variables for each type of activity whose coefficients are estimated. A comparison of these coefficients across all of the activity types shows that social visit and sports/recreation kind of activities have a relatively longer duration than eat out, personal business, shopping and in-home activities. This result is intuitive since the former activity types are more discretionary in nature whereas the latter are of a maintenance kind. Hence, children are probably deriving more utility by spending time in the discretionary activities. The negative coefficient for in-home activities indicates that even if children choose to return home from their fixed (school) activity, they spend relatively less time at home and prefer to spend higher amount of time in discretionary and maintenance activities out of home. A work activity type indicator variable is used only for children who are also workers and the magnitude of its coefficient shows that a relatively high amount of time is spent in working if it is chosen. This is reasonable considering the fact that work is a mandatory activity type and offers monetary benefit as well.

From the coefficients of time of day variables, it appears that activities of all types are pursued for shorter durations as the day progresses after noon. Activities started after 7 PM are relatively shorter than those started between 5 PM and 7 PM which in turn tend to be shorter than those started between 3 PM and 5 PM and so on. This could possibly be due to the reducing time left in the open prism before the evening (end of day) vertex of children. Activities pursued closer to the end of the open prism tend to be shorter considering the constraint of returning home for the travel day. Non-mandatory activities starting between 6 AM and 9 AM are also shorter probably due to the same reason. This period may be closer to the end of the morning open prism before the start of school.

Further sensitivities are revealed through interactions of the time of day with activity type variables. Shopping, sports/recreation and eat out activities tend to be longer if pursued between 5 PM and 7 PM whereas in-home activities are shorter during the same period. This may be due to the tendency of children (and probably accompanying adults) to pursue these kinds of activities later in the day because of higher time availability. This may also be leading to the relatively shorter duration of in-home activities between 5PM and 7 PM. Eat out activities are shorter during 3 PM and 5 PM when compared to those between 5 PM and 7 PM. Eating out during the earlier period may just mean having snacks and not full-fledged meals which is what they might mean in the later period. Social visits made during 3 PM and 5 PM are also shorter probably because it appears that there is a tendency to pursue other non-mandatory activities (shopping, sports/recreation and eat out) for a longer duration later (between 5 PM and 7 PM).

The coefficient for number of children in the household being negative is probably a reflection of additional constraints on the dependent activity being simulated. The presence of other children in the household where ever they may be, either on the trip or at home, could lead to the shortening of the current activity. On the other hand, more number of drivers in the household may potentially result in an opposite effect, a relaxation of constraints on the serve passenger trips made by adults, which in turn may lead to longer activities pursued by dependent children. Children living in households in urban areas tend to engage in activities of that are shorter in duration for all out of home activities except shopping. Again constraints on chauffeuring activities in a household may worsen due to congestion, resulting in shorter activity durations out of home and longer ones in home. Longer shopping durations may be due to the presence of a larger and broader array of shopping opportunities in an urban setting. Low income households (annual income less than $35,000 per year) are found to spend less time in both in-home and sports/recreations activities. Shorter sports/recreation activities may be due to the costs associated which such activities whereas shorter in-home activities may be a result of lack of opportunities to pursue high utility in-home activities in these households. For example, these households may not have high quality cable subscriptions for television or may not own video game systems or computers.

5.6. Joint Activity Engagement Model

The types, locations, and durations of the various dependent activities for children are already determined at this stage of the simulation. This last model in the proposed framework determines whether or not the joint travel episode which has already been generated is also a joint activity episode. In other words, the outcome of this model is the choice of the child to have the accompanying adult stay on for the duration of the activity or not.

Trips from the 2001 NHTS dataset are used for model estimation. As mentioned earlier, though the dataset has information about the specific identities of the accompanying household members on a particular trip, it does not reveal the specific trips reported by those members. A script coded in python is used to decipher this information by matching the trip end and start times along with identity of household vehicle used for the trip. Once the specific trip records of all the household members on a joint trip are identified, it is determined whether or not it was a serve passenger trip based on purposes stated by the involved household members. If the purpose of at least one of the household members on the trip falls in the serve passenger category, then that is trip is denoted as a pick-up/drop off only trip. On the other hand, if the purpose of none of the participating household members belongs to the serve passenger category and the dwell times of all these persons at the activity location are the same, then a joint activity engagement episode is considered to have followed the joint travel episode. Joint trip records of children between 5 and 17 years of age are isolated first and are tagged with an indicator variable for joint activity engagement which serves as the dependent variable. This outcome is modeled as a binary probit formulation and the estimation results are presented in Table 15.

Table 15 Joint Activity Engagement Model

Variable	Coeff	t-stat
Constant	-0.058	-1.0
Activity Characteristics		
In-home activity	2.298	47.4
Work	-0.130	-1.6
Personal business	1.184	24.3
Shopping	2.493	44.5
Social visits	0.888	30.9
Sports and recreation	0.907	30.9
Eat out	2.664	24.0
Dwell time	-0.001	-21.1
Child Characteristics		
Age between 5 and 10 years	0.059	2.9
Race is White	-0.054	-2.0
HH Characteristics		
HH income less than 35k per year	0.109	3.9
Number of drivers	0.101	6.0
HH in urban area	-0.163	-7.2
HH life cycle with 2+ adults	0.104	2.6
Number of observations	42019	
Log likelihood	-10573.56	
Restricted log likelihood	-17903.68	
Chi squared	14660.25	
Estrella	0.36	
AIC	0.50	

In this model, the activity characteristics dominate as explanatory variables when compared to child and household characteristics. This is an intuitive result since it is likely that the outcome of the adult staying on for the activity is more dependent on the type and duration of the activity than on other constraints. The characteristics of the accompanying adult are not included as explanatory variables since the specific identity of the adult is not known at this stage of the simulation. It is envisioned that the schedules of specific household adults are blocked in the next stage of simulation along with the generation of their daily activity choices.

The constant is insignificant indicating that there is no general bias regarding the pursuit of a joint activity by the accompanying adult after a joint travel episode. If the activity type is at home, it influences the adult to stay at home after the trip. Even though it is possible, it is not probable that an adult would go on to pursue another activity immediately after a travel episode terminating at home. If the child is being transported for work related activity, the negative coefficient indicates the adult is unlikely to stay on for the activity. This is quite reasonable considering the fact that a child independent enough to work is probably capable of working independently. In other words, if a child is pursuing a work related activity, he or she probably just requires a ride to the workplace. Joint travel to personal business, shopping and eat out activities is most likely to also result in joint activity engagement. This is intuitive because of the nature of these activities is such that they lend themselves to be pursued jointly with family members. Personal business may be an exception in which case, there is a higher probability that the activity is being pursued mainly for the adult and the child is just tagging along. This is a limitation pertaining to the data and has been recognized earlier. In case of other activity types too such as social visits and sports and recreation, multiple household members are likely to derive utility from their pursuit which is again indicated by the positive coefficients for these activity types. The coefficient of dwell time is negative implying that higher activity duration negatively influences the adult's engagement in joint activity and is more likely to result in just a drop-off of the child. The adult can then pursue his or her own activities before picking up the child at the end of the child's activity. Therefore, it is intuitive that adults may not be available to pursue activities of higher durations jointly with children. Trip distance was also tried as an explanatory variable but was found to be insignificant.

The coefficient of the age category indicator is positive which means that children in the youngest age group are more likely to need adult accompaniment on the activity in addition to that on travel when compared to their older counterparts. Also, children whose race is White are more likely to pursue the activity independently than those belonging to other races.

Among the household explanatory variables, the coefficient of number of drivers is positive implying that if there are more drivers present in the household then the probability of the adult pursuing a joint activity with the child increases. This result is intuitive since the adult who would accompany the child for travel to an activity would be relatively less constrained to pursue other household/serve passenger activities which can be shared by the remaining drivers in the household. A similar argument could be made for the coefficient of a household in a life cycle with two or more adults being positive. There are more household adults that can potentially share the household activity-travel responsibilities thereby increasing the feasibility of the adult under consideration to pursue a joint activity with the child after the travel episode. Adults in low income households (less than $35,000 per year) are more likely to stay with a child to pursue the activity jointly. It is probable that the adults in low income households work fewer hours and hence are more available to pursue activities jointly with children. It is also found the children in households in urban areas are less likely to have adults pursue activities with them jointly. A plausible explanation for this may be that adults in urban areas can potentially engage in more activities than those in the rural areas. So it is a reflection of their availability for pursuing joint activities with children.

6. SIMULATION OF CHILD ACTIVITY-TRAVEL PATTERNS

This chapter presents the results from a test simulation performed to determine the validity and behavioral consistency of the estimated models. Several steps were performed in order to implement the proposed framework. A synthetic population for Maricopa County was generated using Census 2000 data from PopGen 1.1 and school locations for all school-age children were determined using UrbanSim's location choice models. OpenAMOS was the activity-based microsimulation tool used for the implementation of the framework. Figure 9 shows the graphical user interface of OpenAMOS.

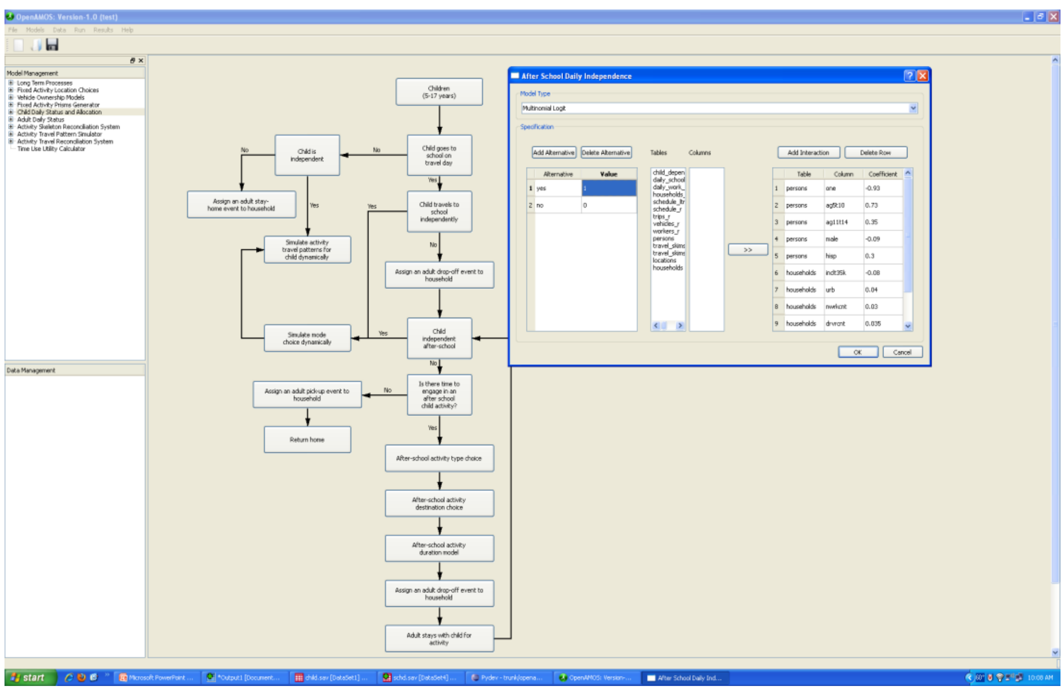

Fig. 9 OpenAMOS Graphical User Interface

The daily morning, evening and school prism vertices were simulated with the help of earlier models estimated in OpenAMOS. The framework of child dependency models was inserted to run after the simulation of daily prism vertices and the model specifications were input into the OpenAMOS microsimulation system in preparation for a test run.

A simulation run for a 5% sample of children (between 0 and 17 years) from the synthetic population was made. The sample consisted of 2,443 pre-school and 5,743 school children. The simulation results are validated against actual numbers from NHTS data. Figure 10 shows the validation results of pre-school daily status. It can be seen that the simulated probabilities are reasonably close to the actual probabilities calculated from NHTS data. Results are compared for overall category of pre-school children and also based on specific age group that a child belongs to.

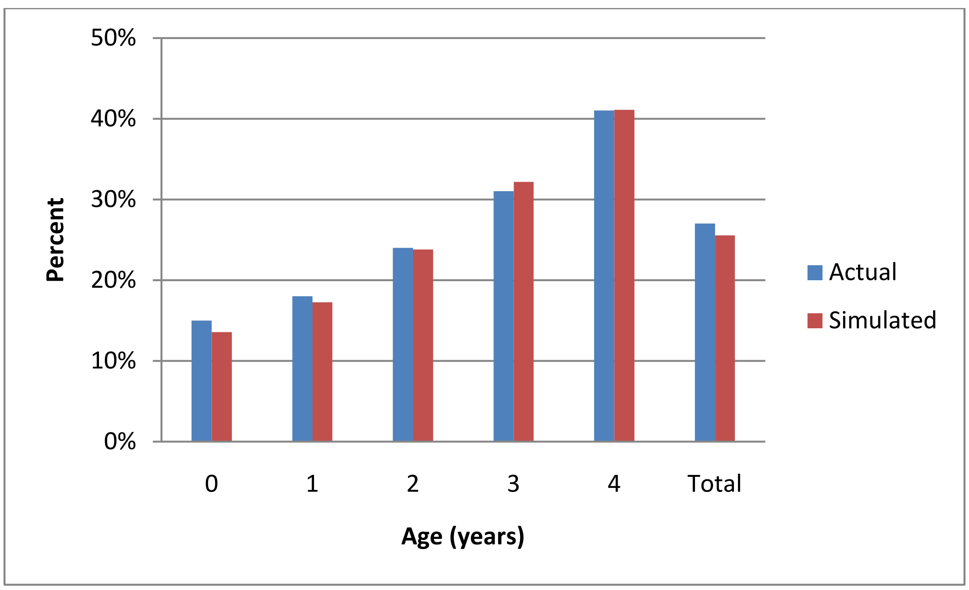

Fig. 10 Validation of Pre-school Daily Status

Figure 11 shows the validation results of school daily status. Again, the simulated fractions of children attending school on a travel day are very close to those found in NHTS.

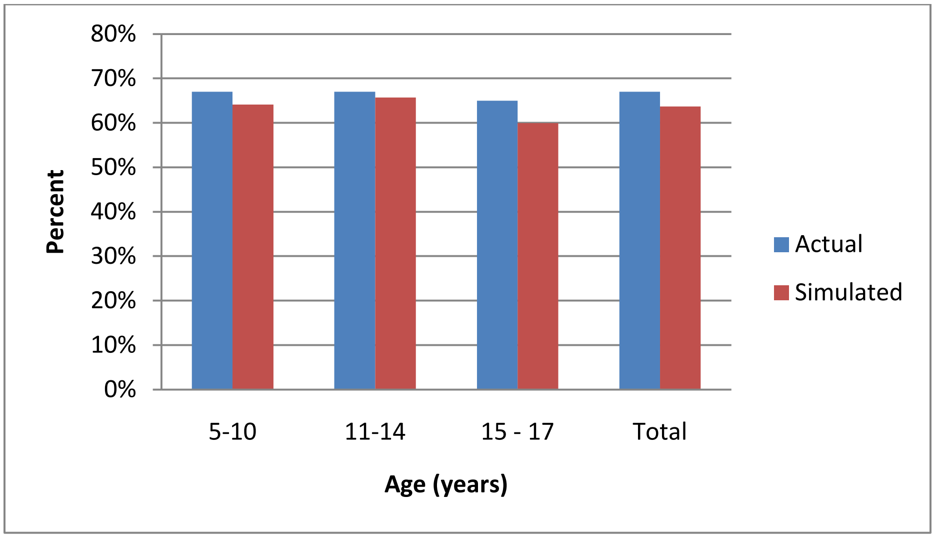

Fig. 11 Validation of School Daily Status

Figure 12 shows the validation of the child dependent status model. It appears that the simulation model consistently over predicts the proportion of dependent children in all the age groups. The reason for this is not obvious and may require further investigation of the sample data and model specifications. Overall, the error is less than 10%.

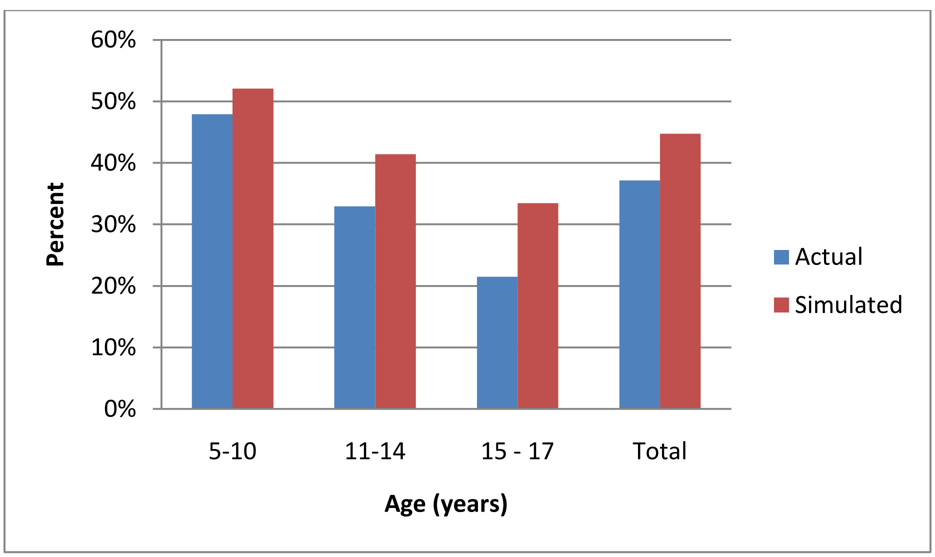

Fig. 12 Validation of Child Dependent Status

Figure 13 shows a comparison of the distributions of children's dependent activity types from NHTS (actual) and the test simulation run (simulated). The fraction of in-home dependent activities pursued is about 15% percent higher in the simulated case. Consequently, proportions of other out-of-home non-mandatory activities are underestimated.

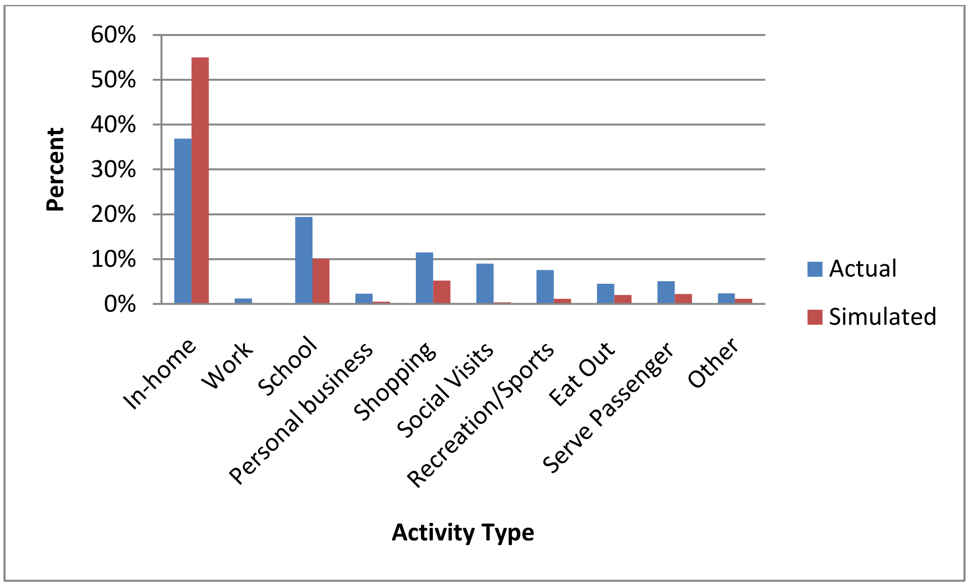

Fig. 13 Validation of Activity Type Distribution

Figure 14 compares the mean activity durations by activity type between NHTS and the simulation test case. On an average, the activity durations of all activity types except the in-home ones are underpredicted. The match in the mean activity durations for school is considerably better probably because they are predicted using time prism vertices based on stochastic frontier models. Another reason may be the less variability in school activity durations when compared to other non-mandatory activities.

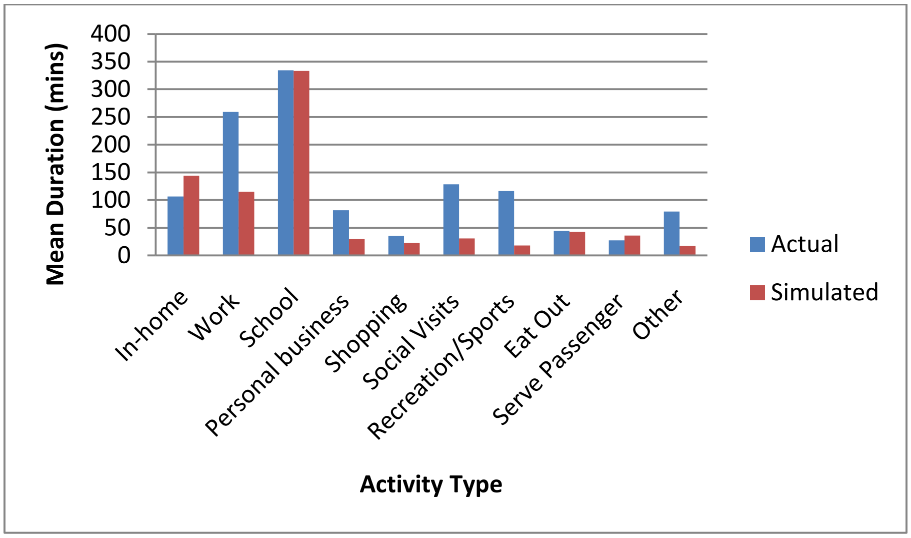

Fig. 14 Validation of Activity Duration

Finally, the resulting dependent activity skeletons were analyzed to test for behavioral integrity. Figure 15 shows sample activity skeletons of seven children from the simulation. In the figure, time is represented on a continuous scale in minutes from 4 AM. In other words, the simulation was initialized at 4:00 AM (0 minutes) and was run until 3:59 AM (1439 minutes) on the next day. On a broader scale, the activity skeletons were found to make behavioral sense. Children seem to be predominantly engaging in activities at two locations – home and school. There are also non-mandatory activities like sports/recreation, shopping and meals that are being pursued after school. The durations of these activities are found to be quite short as shown by the aggregate chart in Figure 14. In a few cases, it can be seen that social and serve passenger activities are being pursued before the school episode. It is possible that some children pursue such activities before the beginning of a daily school episode. The serve passenger activities are generated only for children greater than or equal to driving age (16 years).

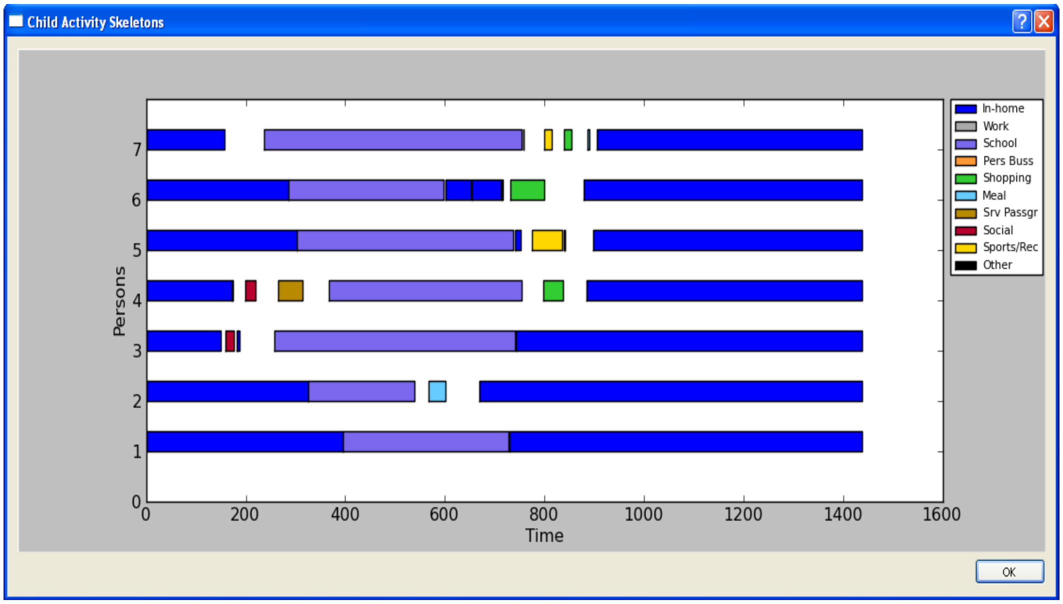

Fig. 15 Sample Dependent Child Activity Skeletons

7. SUMMARY AND CONCLUSIONS

In recent years, there has been a growing concern regarding the activity-travel patterns of children in various fields of research. In transportation, the existence of interdependencies between the activity-travel patterns of adults and children within a household has been recognized. Though there have been several efforts to model these interdependencies much remains to be done. This research is motivated by the need to advance the understanding of the interactions between adults and children in households affecting activity-travel patterns and add to the growing body of literature. It also contributes to the development of a practical modeling framework for incorporating child dependencies in an activity-based microsimulation context.

A quick comparison of socio-demographic values shows that households with children are generally larger than households without children in terms of number of adults, workers, drivers, income, and vehicle ownership. A more detailed comparison of activity engagement and travel patterns of adults living in both households with and without children is done using NHTS data. Adults in households with children make a higher number of home-based other and non-home based trips but relatively lower number of home-based socio-recreation and shopping trips when compared to adults in households without children. They also make 10% more HOV and 10% less SOV trips than the adults in households with no children. The mean trip duration is found to be relatively low for these adults for all activity purposes other than work. Adults in households with children make a 5% higher share of trips both in the morning peak (6 AM – 10 AM) and the evening peak (4 PM – 8 PM) periods of the day than adults in the other group of households. A significantly higher proportion of these adults engage in serve passenger activities when compared to that of adults in households without children (30% as opposed to only 7.1%) on a typical weekday. Adults in households with children engage in less personal business, shopping, and social activities both in terms of frequency and time than their counterparts in households without children.

Tour-based analysis shows that adults in households with children engage in a significantly higher share of complex home-based work tours (those involving stops in either or both directions to and from work). They also make a higher share of simple home-based other tours but not complex ones reflecting the constraints imposed by children on tours with more number of stops. Tour mode share comparison shows the same patterns as those in comparison of trip mode shares. Adults in households with children make a higher share of tours by HOV only and a combination of SOV and HOV modes. In tour accompaniment comparisons, it is found that these adults make a significantly higher share of tours of the partly solo and partly joint kind which indicates a high amount of serve passenger activity. An examination of joint travel characteristics of children between 5 and 17 years shows that more than 50% of all their trips involve household adults. Such trips may be made solely for the adult, solely for the child or for both. In any case, these joint trips need to be explicitly accounted for in activity-based microsimulation models.

A framework involving models to predict/simulate the various daily activity engagement and travel choices of children between 0 and 17 years of age which could potentially create linkages to and constrain adult activity-travel patterns is proposed. The flow and logic of the framework which make it feasible and practical for use in activity-based microsimulation settings given the constraints on the data available are presented in detail. Models comprising the framework essentially simulate the daily school/pre-school attendance, the child dependence for travel purposes, dependent activity type choice, destination choice and duration, and finally the joint engagement of activity with an adult. Each of the models within the framework is a relatively simple formulation and is estimated using NHTS data. However, the combined deployment of the models in a logical sequence as proposed in the framework could potentially facilitate the capturing of complex interactions shaping the activity travel patterns of adults in a household with children.

The probability models for daily school and pre-school attendance show that the probabilities are 0.7 and 0.3 on an average. A binary probit model for simulating the dependent status of a child for travel purposes shows that younger children tend to be more dependent than older ones. Dependence may also be positively influenced by the number of unemployed persons, drivers, and presence of other children in the household. The dependent activity type choice is modeled as an MNL formulation which consists of eight disaggregate activity types as choices. It is found that everything else being equal, pursuing an in-home activity has the highest probability. Apart from various socio-demographics, activity engagement history and time of day variables are found to be significant in the choice of a child activity type requiring adult escorting. An interesting observation is that previous engagement in discretionary activities increases the probability of choice of a subsequent social activity. The destination choice for a particular activity type chosen is modeled as an MNL too. Activity type interactions are found to be significant in addition to zonal characteristics and interactions with socio-demographic variables. The disutility due to travel time is reduced in case of social visit activities and is increased for eat out activities. The activity duration model is a log-linear regression model of the time spent performing an activity in minutes. Again, activity type indicator variables are included in the model specification in addition to their interactions with socio-demographics. It is also observed that time of day of the activities also plays an important role in influencing their durations. The joint activity engagement model is a multinomial probit formulation to simulate the joint pursuit of a dependent activity by a child and adult. It is found that activity type is an important explanatory variable. Joint travel to shopping and eat out activities may be associated with a higher probability of joint activity engagement when compared to other activity types. Other socio-demographics representing the availability of adults are also found to be significant in explaining this process.

A test simulation of the proposed model framework is run using the OpenAMOS activity-based model system with a 5% sample of children from the Maricopa County synthetic population. Validation results show that the probability-based models for pre-school and school daily statuses perform better than the other discrete outcome models. Errors in the predictions of all the models range from 5% to 15%. Overall, the test simulation is found to produce reasonably intuitive child dependent activity skeletons. Multiple runs may be required to better measure the accuracy of this framework.

As mentioned earlier, the simple formulations of constituting sub-models lead to a relatively easier implementation of this framework in an activity-based microsimulation model. It is envisioned that the use of this framework before the simulation of adult daily activity travel patterns can significantly enhance the representation of the interactions and dependencies with respect to children in a household. However, assignment of all the children's dependent activities to household adults in a downstream process may not be a trivial task. Spatial and temporal consistency checks along with robust schedule conflict resolution strategies need to be developed and tested in future studies. Future work may also explore the feasibility and practicality of more complex econometric formulations such as multiple-discrete and/or joint discrete-continuous models for activity-travel dimensions. A more thorough and complete validation of this framework using multiple simulation runs may be necessary before its use in planning applications. In any case, it is recommended that future activity-based microsimulation models incorporate such a framework to explicitly account for children's influences and interactions within households.

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