Children's Activity-Travel Patterns and Implications for Activity-Based Travel Demand Modeling

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ABSTRACT

The analysis of children's activity-travel patterns and time-use is gaining increasing attention in several fields. This paper discusses the treatment of children within current activity-based travel demand modeling systems and conceptualizes an alternative framework for simulating the daily activity-travel patterns of children. Overall, the research effort details the current state of children's travel behavior analysis and highlights areas for future research.

1. INTRODUCTION

The analysis of children's activity-travel patterns and time-use has been gaining increasing attention in a variety of fields, driven primarily by three main considerations: (1) Encouraging children's participation in developmentally beneficial activities; (2) Promoting the health of children by increasing participation in physically active activities and non-motorized travel; and (3) Understanding children's activity-travel behavior and its implications for the accurate forecasting of the overall travel patterns of individuals in a household, within the context of an activity-based approach to travel modeling. The first issue above has received substantial attention within the sociology, child psychology, and child development fields, with previous research in these fields contributing to our understanding of children's overall time-use and participation rates, as well as participation in specific activity types such as leisure activities and after-school programs (see, for example, Hofferth and Sandberg, 2001; Bianchi and Robinson, 1997; Barnes *et al.*, 2007). The second issue has been studied at the interface of the transportation and public health fields, because of the positive correlation between physically active lifestyles and the development of strong, healthy, and intelligent children (CDC, 2006; Transportation Research Board and Institute of Medicine, 2005). Specifically, previous research in these fields has examined the extent, duration, and instances of participation in physically active activities and non-motorized travel, especially with regard to mode choice to school (see, for example, McDonald, 2005; Mackett, 2001; McMillan, 2007; Copperman and Bhat, 2007a). The third issue has been a growing subject of study among activity-based travel modelers (see Copperman and Bhat, 2007b; Sener and Bhat, 2007; Stefan and Hunt, 2006). However, many activity-based travel demand modeling systems currently in practice or in development still take a limited approach to modeling the patterns of children and make many simplifying assumptions (see Section 3.1 for further details on this point).

The focus of this paper is on the third issue just discussed, which is to examine children's activity participation behavior in the context of accurate travel forecasting. The next section discusses the characteristics of children's activity-travel patterns and the limitations of current activity-based travel demand models to addressing these characteristics. Section 3 presents an analytic approach to modeling children's weekday activity-travel patterns that addresses these limitations. Note that the children's activity-travel generation process presented in Section 3 is designed to interact with an activity-travel generation process for adults, other household

members, and even non-household members. The process positions the children-related models within other household members' activity-travel generation process, but does not discuss in detail the adult and household activity-travel generation process. The paper also identifies the need and opportunities for further research in the field of children's travel behavior analysis.

2. CHARACTERISTICS OF CHILDREN'S ACTIVITY-TRAVEL PATTERNS AND THE TREATMENT OF CHILDREN WITHIN ACTIVITY-BASED TRAVEL DEMAND MODELS

2.1 Intra-household Interactions

An important limitation of current activity-based modeling systems is the inadequate consideration of intra-household linkages related to escort trips and partial/joint travel between children and adults. Given that car trips make up 65.7-75% of all children's trips, joint and partially-joint tours with an adult driver make up a very high percentage of children's travel (McDonald, 2005; Cain, 2006; and Weston, 2005). The percentage of car trips is even higher on weekends. Children make approximately 80% of their weekend trips by car (Weston, 2005; Stefan and Hunt; 2006).

The activity-based model systems developed for Dallas, South Florida, Atlanta, Columbus, and the San Francisco Bay Area do consider intra-household interactions between parents and children for drop-off and pick-up from school, and for fully joint tours, where all trips within the tour are made together (see Pinjari *et al*., 2006; Pendyala *et al*., 2005; Vovsha *et al*., 2003; PB Consult, 2005; Vovsha and Petersen, 2005; and Bradley and Bowman, 2006). However, none of the activity-based travel demand models currently in implementation or under development explicitly model partially joint tours (*i.e.* tours in which one or more passengers is dropped off or picked up mid-tour) for non-mandatory (*i.e.* non-school or non-work) activities (Bradley and Bowman, 2006). On the other hand, partially joint tours make up close to 14% of all tour types in metropolitan areas (Vovsha and Petersen, 2005).

Due to the limitation discussed above, current activity-modeling systems fail to link escorting, or serve-passenger, stops among household members for non-school trips. If an adult household member is scheduled to make a serve-passenger stop, it is unknown who s/he is dropping off or picking up. In addition, if a child is scheduled to be driven to an activity, it is not known whether or not s/he is taken by a household member or a non-household member. In

addition, due to the escort-dependency of children, partially joint tours are likely to make up a much higher percentage of tours for children and mothers, who are known to bear a higher percentage of the escorting responsibility compared to fathers (McDonald, 2005; Sener and Bhat, 2007; Yarlagadda and Srinivasan, 2007). A first step toward accurately modeling these partially joint tours between children and their escorting parents is to understand the temporal and spatial dimensions of activities involving child-escort activities, as discussed next.

2.2 Activity Typology and Level of Fixity

2.2.1. Children's Activity Purposes

Children's activity purposes include habitual and mandatory activities that take place on a regular basis and have a relatively set time period of participation (*i.e.* personal care, sleep, and school on weekdays), and non-mandatory activities whose participation rates and duration levels show more variation by day and by child. Exact classifications of the non-mandatory activity purposes vary from study to study in earlier research, but they can be loosely classified as: 1) Non-structured (or free play) recreation and social activities, 2) Organized or structured activities, 3) Studying/homework, 4) Paid work, 5) Receiving childcare, 6) Personal business or shopping, and 7) Meals.

Non-Structured Recreation and Social Activities Non-structured recreational activities include unorganized hobbies and sports, outings, playing, television viewing, and music. Almost all children spend some amount of time participating in non-structured recreational activities each day and spend more time in these activities on both weekdays and weekend days compared to any other non-school activity (Copperman and Bhat, 2007b). Copperman and Bhat (2007b) found that children who recreate, spend, on average, 3 ½ hours per day on the weekday and 6 ½ hours on the weekend in non-structured recreational activities.

With regard to specific types of non-structured recreational activities, television viewing has the highest participation rates and duration of participation. Ninety percent of children watch television at least once a day for on an average of 2 ½ hours per day, with higher durations on weekend days (Hofferth and Sandberg, 2001; Bianchi and Robinson, 1997; Shann, 2001; Copperman and Bhat, 2007b; Barnes *et al.*, 2007; Zill *et al.*, 1995; Rideout *et al.*, 2005). Approximately 15-22% of children participate in hobbies each day for about an hour per day

(Hofferth and Sandberg, 2001; Copperman and Bhat, 2007b; Zill *et al*., 1995). As for physical activity participation, approximately 14% of children participate in non-structured physical activity on weekdays and 22% of children participate in non-structured physical activity on weekend days (Sener *et al*., 2008). Children who participate in recreational physical activity participate for ½ hour to 2 hours per day (Hofferth and Sandberg, 2001; Sener *et al*., 2008; Larson and Verma, 1999). In addition, participation rates and duration levels in physically active recreation are higher for boys than for girls (Gibbons *et al.*, 1997; Shann, 2001; Larson and Verma, 1999; Kohl and Hobbs, 1998; Sallis *et al*., 2000; Barnes *et al*., 2007).

Social activities include conversations, being intimate, parties, and visiting. Copperman and Bhat (2007b) found that 37.5% of children participate in social activities for over an hour on weekdays and over 60% of children participate in social activities on the weekends for over 2 hours per day. However, it should be noted that Copperman and Bhat (2007b) include religious activities as a social activity and, therefore, durations and participation rates in pure visiting activities are likely to be lower, especially on weekend days.

Organized Activities Organized activities involve a regular participation schedule, are led by an adult activity leader or coach, emphasize skill-building, require sustained attention, and include performance feedback (Mahoney and Stattin, 2000; Sener *et al*., 2008). These activities include extracurricular pursuits, lessons, enrichment activities, youth groups, meetings, clubs, and organized games and meets. Participation rates per day range from 11-12% for young children to 22-23% for adolescents (Hofferth *et al*., 1991; Copperman and Bhat, 2007b). Children who participate in organized activities spend 1 ¾ hours per day on weekdays and 2 ¼ hours on weekends (Copperman and Bhat, 2007b; Barnes *et al*., 2007).

While not considered within the statistics above, religious activities are another form of organized activity. Approximately ¼ of elementary and middle school children and over ⅓ of high school children attend religious activities at least once a week (Hofferth and Sandberg, 2001; Huebner and Mancini, 2003; Zill *et al.*, 1995). Hofferth and Sandberg (2001) found that children participate in religious activities for approximately 1 ½ hours per week. Most likely, a high percentage of these religious activities occur on the weekend, due to the predominance of religious services and religious school taking place on Sunday. In addition, two studies reveal

that black children participate, and spend more time, in church-related activities compared to other racial groups (Hofferth and Sandberg, 2001; Huebner and Mancini, 2003).

Some studies have examined participation in organized/structured physical activity. Zill *et al*. (1995) report that approximately 13% of high school students take sports lessons at least once per week, while Sener *et al.* (2008) found that 9% of children participate in an out-of-home structured physical activity on weekdays and 6% of children participate in an out-of-home structured physical activity on weekends. Children who participate in structured physical activities participate, on average, for 1 ¾ hours on weekdays and for 2 ¼ hours on weekends.

Studying/Reading Several studies have examined participation levels in studying, homework, and reading. These studies have found that between 40-62% of children study on a daily basis on weekdays (Hofferth and Sandberg, 2001; Bianchi and Robinson, 1997; Copperman and Bhat, 2007b). Several studies separated reading from studying, and reveal that 20% of adolescents, 34% of children aged 9-12, and 43% of children aged 6-8 read on a daily basis (Hofferth and Sandberg, 2001; Zill *et al*., 1995). Significantly less children study on the weekends. For instance, Copperman and Bhat (2007b) found that only 16.5% of children study on the weekends.

Time spent in studying also differs by age and gender. High school and middle school children spend over 1 ¼ hours studying on weekdays, while elementary school children spend only 30-50 minutes per day studying (Copperman and Bhat, 2007b; Barnes *et al.*, 2007; Larson and Verma, 1999; Hofferth and Sandberg, 2001). With regard to gender, girls spend more time studying than boys (Fuligni and Stevenson, 1995; Medrich *et al.*, 1982; Timmer *et al.*, 1985; Harrell *et al*., 1997; Barnes *et al.*, 2007). While fewer children study on the weekend, children who do study on a weekend day spend a longer period of time studying than they do on a weekday (Copperman and Bhat, 2007b).

Work Only high school students (*i.e.* children aged 15 and older) work at a paid job (O'Brian and Gilbert, 2003; McDonald, 2005). Copperman and Bhat (2007b) found that 12% of high school students work, on average, for 4 1/3 hours per day on weekdays, and 6 hours per day on weekends. Zill *et al.* (1995) determined that 27% of 10^{th} graders and 60% of 12^{th} graders work for at least 7 hours per week. In addition, Barnes *et al.* (2007) observe that adolescents work, on average, for 8 hours per week, while Larson and Verma (1999) report work duration hours at

levels of 10-20 hours per week. The differences in daily compared to weekly participation and duration rates is most likely due to adolescents working two to three days a week for several hours, rather than working every day for shorter periods of time.

Receiving Childcare Receiving childcare is an activity that is specific to elementary school children (Hofferth and Sandberg, 2001; McDonald, 2005; Hofferth and Jankuniene, 2001; Copperman and Bhat, 2007b). In particular, about 13% of elementary school children attend daycare or receive childcare on weekdays and less than 4% of elementary children attend daycare on weekend days (Hofferth and Sandberg, 2001; Copperman and Bhat, 2007b). Time spent in childcare average 2 hours on weekdays and 1 hour on weekends (Copperman and Bhat, 2007b).

Personal Business Very few studies have examined children's participation levels in personal business activities. Copperman and Bhat (2007b) found that 23% of children on weekdays and 41% of children on weekends participate in some form of personal business. During the week, children spend about 50 minutes per day in personal business activities, while on weekends children spend about 1 ½ hours.

Meals All children spend some amount of time eating either as the primary activity or in combination with other activities. Children spend about an hour per day eating, with slightly higher durations on weekends (Hofferth and Sandberg, 2001; Copperman and Bhat, 2007b). Approximately 3% of meals occur at a restaurant on weekdays and 5% of meals occur at restaurants on weekends, suggesting that 3-5% of meals can be classified as "eat-out" activities (Copperman and Bhat, 2007b). Rate of participation in eat-out activities varies by household income, with children from higher income households eating out more (McDonald, 2005).

2.2.2. Activity Classification in Current Activity-Based Travel Demand Modeling Systems

Current activity-travel demand modeling systems classify activities into categories that are oriented toward the activity engagements and priorities of adult household members, but ignore differences between the activity types and activity dimensions of children and adults. For instance, modeling systems designed for New York, Atlanta, and Columbus classify activities

into three broad purpose categories: mandatory activities (including going to work or school), maintenance activities (including shopping, errands, medical appointments, *etc.*), and discretionary activities (including social and recreational activities, eating out, *etc.*) (see Vovsha *et al*., 2003). These activity categories are assigned a scheduling priority, with mandatory activities taking precedence over maintenance activities and maintenance activities taking precedence over discretionary activities. For an adult household member, such a prioritization may not be unreasonable. However, this prioritization and activity classification is not appropriate when characterizing and representing the activity needs and pursuits of children. While it is still appropriate to separate mandatory activities from non-mandatory activities, the activity typology breaks down when one attempts to divide children's non-mandatory activities into maintenance and discretionary activities and give priority to maintenance activities over discretionary activities. First of all, children may not have any out-of-home maintenance needs. If the child participates in a maintenance activity, it may be a parent's activity rather than the child's. Second, organized and structured activities do not easily fit into one of the three assigned categories. In most activity-travel surveys and current activity-travel demand models, organized activities would be considered a recreational activity, and therefore a discretionary activity, according to the traditional classification scheme. However, organized activities are more similar to mandatory activities with fixed start and end times, fixed locations, and a regular participation schedule. But, unlike school and work, such organized extracurricular activities tend to be shorter in duration and exhibit greater variation in spatial and temporal activity participation attributes across children. In addition, work and school activities also have a higher obligatory status associated with attendance compared to extracurricular activities. Further, it can be argued that, for a child and an escorting parent, an extracurricular activity (such as a music lesson or soccer practice) will take precedence over running errands and grocery shopping. These activities are pre-planned and failure to participate may result in a cost to the parent or child.

Other activity-based models classify activities into finer purposes than those used in New York, Atlanta, and Columbus (see, for example, Pendyala *et al*., 2005; Pinjari *et al*., 2006; and Bradley *et al*., 2007). But several activity purposes that are ubiquitous for children are left out all together, such as studying and childcare. Also, even with this fine activity classification

scheme, the question still remains regarding how to fit extracurricular activities into the taxonomy.

Overall, earlier activity-based systems have used activity purpose flexibility in time and space as the basis for determining activity priority in scheduling. Such a concept is not new, and dates back to Cullen and Godson (1975), who proposed that there are different degrees of commitment to an activity, and this degree of commitment is related to the degree that an activity is fixed in time and space. Cullen and Godson set out four levels of degrees of commitment: a) arranged activities with other people where the time and place of the activity is usually fixed, b) routine activities that are undertaken at the same time and place each day, c) planned activities for some future but not set point in time, and d) unexpected activities that are not pre-planned and do not have any fixity in time or space. For the case of children, extracurricular activities would fit into the first category, while such activities as in-home personal care and sleeping would be a fixed activity as defined by the second category. Cullen and Godson (1975) further theorize that activities an individual is strongly committed to, and that are fixed in time and space, act as a peg around which other activities are planned. Frusti *et al*. (2003) also highlight the importance of fixed activities in determining how responsive an individual will be to a change in transportation policy. Frusti's study found that children and students have the highest number of non-work/non-school fixed activity commitments. These results, again, point to the need to create a different activity typology for children and adults.

3. CHILDREN'S DAILY ACTIVITY-TRAVEL PATTERN GENERATION PROCESS

This section presents an analytic approach to modeling children's weekday activity-travel patterns that addresses the limitations of current modeling systems. Note that the children's activity-travel generation process presented is designed to interact with an activity-travel generation process for adults, other household members, and even non-household members. The process positions the children-related models within other household members' activity-travel generation process, but does not discuss in detail the adult and household activity-travel generation process.

3.1 Activity Typology

As discussed above, activity typologies utilized in current activity-based travel demand models are limited in their ability to represent children's activities and their associated dimensions, because they use a common taxonomy for children and adults. On the other hand, an important difference between children's and adults' patterns is that children participate in a higher number of non-school/non-work, but fixed, out-of-home activities. Similar to school, these fixed, or structured, activities tend to be planned in advance, are fixed in both time and space, and take place on a regular basis. They are obligatory in nature and, therefore, take a high precedence, directly behind school participation, in an individual and his/her escort's time-use scheduling. The activity typology, as described below, defines a separate structured non-school activity category to account for the salient characteristics of activities in this category.

The activities that a child undertakes during the course of a day can be classified into three broad types: school, structured, and non-structured. The school activity includes participation in school classes, but does not include before-school or after-school activities that take place at school. The school activity has many dimensions that are similar across all children. School is a highly obligatory (or mandatory) activity, occurs regularly every weekday, and has a fixed duration, start and end time, and location. Although for most children school is an out-of-home activity, it can be an in-home activity if a child is home-schooled. The school activity also has a unique *school bus* mode that is not available for other activities, increasing the importance of modeling the school activity and its associated dimensions separately from other activity types.

Structured activities are activities besides school that typically have a fixed start and end time and take place at a fixed location. Examples of out-of-home structured activities include work, daycare, organized clubs, religious school or services, lessons, and organized games or competitions. In-home structured activities include sleep and personal care. Children tend to have regularly scheduled bed times, which are typically preceded and followed by personal care activities such as brushing teeth and taking a shower. Structured activities are also highly obligatory (with a priority-level just below school) since, in many cases, non-participation results in a financial, emotional, or physical cost. These activities also occur on a regular basis and, therefore for out-of-home activities, the travel arrangements are generally planned in advance.

Finally, non-structured activities are other discretionary activities that do not have a fixed start or end time and are flexible in activity location and duration. The obligatory nature of these activities varies by activity type and by individual, but, since they tend to be flexible in time and location, they can be scheduled around structured activities. These include activities such as visiting with friends, meals, studying, and unstructured recreation. These activities also include participation in a household's or other household members' discretionary activity. For example, if a child accompanies his/her mother for a shopping trip, it would be considered a non-structured activity for the child.

3.2 Weekday Process

The activity typology defined in the previous section is used to develop a plausible hierarchical process for modeling a child's weekday activity generation and schedule process (Figure 1).[1] The obligatory dimension and level of temporal, spatial, and inter-personal fixity determines the order in which activities are modeled. The school activity is generated first, followed by structured activities, and then non-structured activities. All dimensions of the school activity, with the exception of mode choice and accompaniment arrangement from school, are modeled before any dimension of the other activity categories is modeled. Mode choice and accompaniment arrangement from school is placed last in the modeling sequence, since a child's choice of mode and accompaniment depends on the generation and scheduling of after-school activities (see Section 3.2.4 for further discussion).

3.2.1 School Generation and Scheduling

The first activity that is generated and scheduled is the school activity (see Figure 2). Similar to work for working adults, school-aged children participate in school during the work week. School is a highly obligatory (or mandatory) activity, occurs regularly every weekday, and has a fixed duration, start and end time, and location. Therefore, for most children, school is a rigidly constrained activity around which all other weekday activities must be scheduled.

On a normal weekday, approximately 87% of children attend school. The time at school comprises the highest percentage of a child's waking hours, averaging 7 hours per day for U.S.

[1] A child's weekend day activity generation and scheduling process may be developed with minor, but important, changes to the weekday process. We do not discuss the weekend process in this paper due to space constraints.

children (Copperman and Bhat, 2007b). Ninety percent of U.S. school-going children start school between 7 and 9 am, and 90% of school-going children end school between 1 and 4 pm[2]. Thus, school tends to occur during the morning and early afternoon, leaving the late-afternoon and evening to pursue a variety of other activities. Therefore, it is not surprising that children participate in all non-school activities, with the exception of personal care, at a much higher rate and for longer durations during the after-school period than the before-school period (Copperman and Bhat, 2007b).

The school activity has start/end times and locations that are determined based on the household's residential choice decision. The school system in which the child attends determines the start and end time of the school day and, therefore, within this framework the school start/end time and location are considered fixed and pre-determined (that is. the household residential choice is modeled prior to the modeling of the daily activity-travel patterns of individuals). The first process that is modeled is *school participation*, which determines whether or not the child attends school on the school day. This model is applied before the parents' work participation during the day and work start/end time models. A child's participation in school is not likely to depend on a parent's choice to stay home from work, but if a child is unable to attend school on the school day, then a parent may have to stay at home from work to attend to the child (see Pinjari *et al*., 2006; PB Consult, 2005).

The next dimension modeled within the school activity is school *mode choice and accompaniment to school*. As discussed in Section 2.1, non-driving age children depend to a large extent on their parents to drive them to activities. Therefore, this model should be applied after a parent's work participation and start time model, and in conjunction with the working parent's commute mode choice model and other school-going siblings' mode choice and accompaniment arrangement models (see Pinjari *et al*., 2006). Depending on a working parent's desired work start time (which the worker may, or may not, schedule to coincide with the child's school start time) a parent may decide to escort a child to school. If a child is not escorted to school by a parent, then the parent may decide to take transit to work since he or she does not need to make a stop on the way to work. However, if a parent must escort a child to school, he or she is likely to choose to drive. The parent may also choose to escort more than one child to

[2] This statistic is calculated using the 2002 CDS-II survey of the PSID. See Copperman and Bhat (2007b) for survey and sample information.

school. Thus, the mode choice of a parent to work and the mode choice of children to school are explicitly related and, therefore, should be jointly modeled.

Given that children are escorted by their parents on many trips, it is not surprising that auto is the dominant mode for school trips, comprising 54% of school trips. School bus trips also make up a high proportion of school trips. McDonald (2005) found that 30% of school trips are made by school bus. Approximately, 11-15% of school trips are made by walking. In both the United States and Canada, school bus trips make up an even higher share of school trips for middle school students compared to elementary and high school students (Weston, 2005; O'Brien and Gilbert, 2003). In addition, middle school students travel the most by walking and biking (McDonald, 2005; Stefan and Hunt, 2006). Similar to children's overall trip-making across all different purposes, biking and transit make up the lowest percentage of trips to school (McDonald, 2005).

The *mode choice and accompaniment to school* model, depending on the availability of modes in the study area and data availability, would include alternatives such as walk, bike, school bus, transit, drive-alone, and passenger in car. Walk, bike, and transit should further be divided into the following categories: with mother, with father, with sibling, with other household member, with friend, with friend's parent, and with other non-household member. The decision to include both household and non-household members in the choice set stems from findings that it is not just household members that accompany children on trips. For example, Clifton (2003) found that 33% of teenagers are accompanied by household members directly after school, while 37% of teenagers are accompanied by non-household members. Weston (2005) observed that older siblings accompany children aged 13-15 on over 4% of trips, while other friends' parents escort children on 8% of trips.

3.2.2 Structured Activity Generation and Scheduling

The next process is the *structured activity participation* model (see Figure 3). This model determines the number of structured activities a child participates in on the activity day. Structured activities have set start and end times, durations, and locations. They tend to be inflexible in the ability to reschedule the activity since more than one or two people are involved. Thus, structured activities constitute a "peg" around which other activities are scheduled. For example, if a child has soccer practice and relies on the mother for transport, then any activities

that the mother participates in will be scheduled around transporting the child to soccer practice. Therefore, this model has to be applied before the maintenance and discretionary activity participations of adults are determined.

The structured activities modeling begins with whether or not a child participates in any structured activity episode, followed by (or jointly with) the structured activity type model (Figure 3). This latter model determines the type of structured activity a child participates in, which may include sleep, personal care, work, daycare, lessons, sports practice and games, religious school, and other clubs and meetings. Next, the *duration* and *time-of-day* of the structured activity is determined. Both of these activity dimensions may be determined jointly. For example, soccer practice may last 2 hours and may take place immediately after school. Alternatively, it may be the case that the time-of-day pre-determines duration of the activity, as in the case of attending religious school which occurs on Sunday morning.

Next, the structured activity *location* dimension is modeled. Since specific activity types are already determined, the location model may include alternatives that are defined by the structured activity type modeled. For example, religious school will usually take place at a religious building (*i.e.* church, temple, monastery, *etc.*). Therefore, the location model may include only religious buildings in the child's neighborhood, or include only zones containing religious buildings. The extent of detail in the location alternatives will depend on the geographical data available for the study region. In this case, it is important to understand the locations where activity types take place, so that these specific location types can be narrowed down as alternatives.

Once the temporal and spatial dimensions of the structured activity type are modeled, the inter-personal attributes may be modeled. These include the *with-whom* and *mode choice and accompaniment* dimensions. First, it is determined with-whom an individual participates in an activity. The *with-whom* model determines if another individual participates in the entire activity with the child, while the *mode choice and accompaniment* model determines if an individual travels with the child to get to the activity. The alternatives of the *with-whom* model should include alone, mother, father, sibling, other household member, or a friend. The results of this model, as well as the transportation options for the study area, determine the alternatives for the *mode choice and accompaniment* model.

3.2.3 Non-Structured Activity Generation and Scheduling

The models related to generation and scheduling of non-structured activities are modeled next. These models include the *non-structured activity participation*, *type*, *time-of-day*, *duration*, *location*, *with-whom,* and *mode choice and accompaniment* models. These models are applied after the models that generate and schedule the household's and other household members' maintenance and discretionary activities. Since the child's non-structured models are not mandatory, and do not have fixed start times and durations, these activities are scheduled after a parent has scheduled his or her activities. For example, if a child wants to go play at a friend's house but relies on the parent to transport him/her to the activity, then the parent may transport him/her on the condition that he/she waits until after the parent has returned home from the grocery store. At the same time, a family may decide to go out to eat that night. This is a joint activity between parents and children and is scheduled before any additional discretionary activities of the children. This joint activity is included as a non-structured activity and the dimensions of the activity are included in the child's activity-travel pattern once the structured activity dimensions are modeled.

The non-structured activity types are classified into household's activities, other household members' activities, and child's activities (see Figure 4). The first two activity types have dimensions that are determined either at the household level or in another household member's generation and scheduling process. The only dimension that is modeled specifically for the child is *participation*. For example, a sibling may have a piano lesson. The only decision that involves the child is whether or not s/he accompanies the sibling to the piano lessons and stays there while the sibling takes the lessons. If, on the other hand, the child accompanies the mother in dropping the sibling off at the piano lesson, then the child's activity would also be "other household member's activity", but in this case it would be the mother's activity rather than the sibling's activity in which the child is also participating. In both instances, the activity type, duration, with whom, and accompaniment arrangement would be pre-determined.

Within a child's non-structured activity, the activity type is further modeled. Possible alternatives for *activity type* are watching television and playing video games, studying/homework, eating, chores, visiting with friends, shopping, personal business, non-organized physical activity, and other recreation. Further research should be conducted to determine appropriate activity type alternatives that share salient attributes.

The other activity dimensions include *time-of-day*, *duration*, *location*, *with-whom,* and *mode choice and accompaniment.* These models are similar in alternative and order of modeling as the structured activity process. One exception is that in the non-structured activity process, *time-of-day* is considered to be determined before *duration*. The intuition behind this arrangement is that unstructured activities are flexible in duration and, therefore, the amount of time spent in the activity would depend on when the activity is scheduled. For example, in the case of television viewing, a child may choose to watch television before leaving for school, but since this activity is scheduled in the morning before the school activity, the child only has a limited amount of time to spend in the activity. Alternatively, if the child chooses to watch television after school, s/he can spend a much longer time participating in the activity.

3.2.4 After-School Mode Choice and Accompaniment Dimension

The final dimension that is modeled is the *after-school mode choice and accompaniment arrangement* model. The reason that this dimension is modeled last is because the possible alternatives depend on the activities, and timing of activities, that a child participates in after school. If a child has a scheduled structured activity directly after school in which a friend's parent is scheduled to drive, then the mode choice from school is already determined. If a child is involved in a sequence of non-structured activities with his or her parent directly after school, then the mode choice from school may be drive-by-parent. Finally, if a child does not have any activities scheduled after school, or has activities scheduled later in the day, then the mode choice from school to home needs to be explicitly modeled.

In actuality, a child's mode choice from school may be pre-decided before any other activities are scheduled. If both parents work, then a child may have to take the school bus home from school, independent of whether s/he participates in after school activities. However, the fact that the parents are unable to drive the child home from school will also affect whether the child is able to participate in other activities, and if these factors are taken into account, the scheduling process will not schedule the child in any out-of-home after-school activities and the mode choice from school to home will be scheduled correctly anyway.

3.2.5 Generation and Scheduling of Tours and Stops

There are many different methods to model the generation of tours and stops for each individual's travel pattern. The formulation of a detailed process is beyond the scope of this paper. However, this section presents a conceptual ordering of the formulation of tours and stops. First, the partial school tour may be modeled by assigning the school activity within the school tour and determining mode choice to school. Once it is determined if a child undertakes an out-of-home structured or non-structured activity before school or after school, the mode choice and accompaniment model of these activities can include an indication of whether the activity is performed as a stop within the school commute, or whether it is contained within a separate tour. Since non-structured activities are scheduled after structured activities, the dimensions of non-structured activities may be designed in such a way as to take place within the same tour as a structured activity. Finally, as defined by the process, mode-choice from school is modeled after all other activities are scheduled. Therefore, the school tour is completed once this dimension is modeled. Dependent on the presence and timing of after-school out-of-home activities, the school tour may or may not contain stops on the way home from school.

4. STUDY IMPLICATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

It is evident from the comprehensive review of the research undertaken on children's activity-travel patterns that children should be studied and treated as a distinct group in the context of activity-based modeling. Further, the conceptualized generation process for modeling children's activity-travel patterns that is presented in Section 3 provides a new perspective to modeling children that is not currently considered in activity-based travel demand modeling systems. However, despite the extensive previous research on children's activity-travel patterns, considerable research is still needed to better understand children's activity-travel behavior, much of which may require refinements to existing metropolitan area travel surveys. The rest of this section discusses the major findings of this research effort and their implications for activity-based travel demand modeling and travel survey improvements. The section also suggests directions for future research based on the findings.

First, as revealed in Section 2 and discussed in detail in Section 3, children have activity-travel characteristics that are unique and different than adults. For instance, they participate in higher levels of structured/organized activities and in unique activity purposes such as daycare

and studying. They also depend on adults to escort them to/from out-of-home activities. These distinctive dimensions of children's activity-travel patterns should be considered and directly modeled within activity-based travel demand modeling systems. In addition, metropolitan area travel surveys should include activity classifications that are more representative of children's activities. If a travel survey groups organized activities into the recreational category, then salient characteristics that differentiate structured activities from other recreational activities is lost. Future research should be conducted to further determine appropriate activity type alternatives that share salient attributes, especially with regard to non-structured activities.

Second, while not unique to children, activities take place both within and outside the home and at various activity locations. What is unique to children is the role school plays as a significant location for out-of-home activity participation for both school and non-school activities. With the advent of advanced spatially disaggregate GIS systems, it is becoming more feasible to perform location modeling at the parcel level. Therefore, assessing the location of activity participation within a certain location type setting (for example, school, someone else's home, own home, *etc.*) will contribute to more accurate geographic location modeling within activity-based travel demand modeling systems. To facilitate the study of location, travel surveys should collect detailed geospatial information.

Finally, a child's activity-travel pattern is impacted by not only household members, but also friends and other non-household members. Studies reveal that the level of children's activity participation with non-family members in activities at someone else's home is quite high. These results highlight the need to examine children's inter-household interactions, as well as children's intra-household interactions, within a joint framework. Travel surveys should better incorporate questions on with whom individuals travel and participate in activities with, as well information on the social networks, and location of social networks, that comprise an individual's daily social contacts.

In conclusion, this paper provides a comprehensive review of previous research on children's activity engagement and travel by focusing on the dimensions of children's activity-travel patterns. In addition, the research effort highlights the limitations of current activity-based travel demand modeling systems with regard to children and provides a new approach for simulating the activity-travel patterns of children. Overall, this research effort details the current

state of children's travel behavior analysis and highlights areas of future research for travel demand modelers, survey developers, and transportation researchers.

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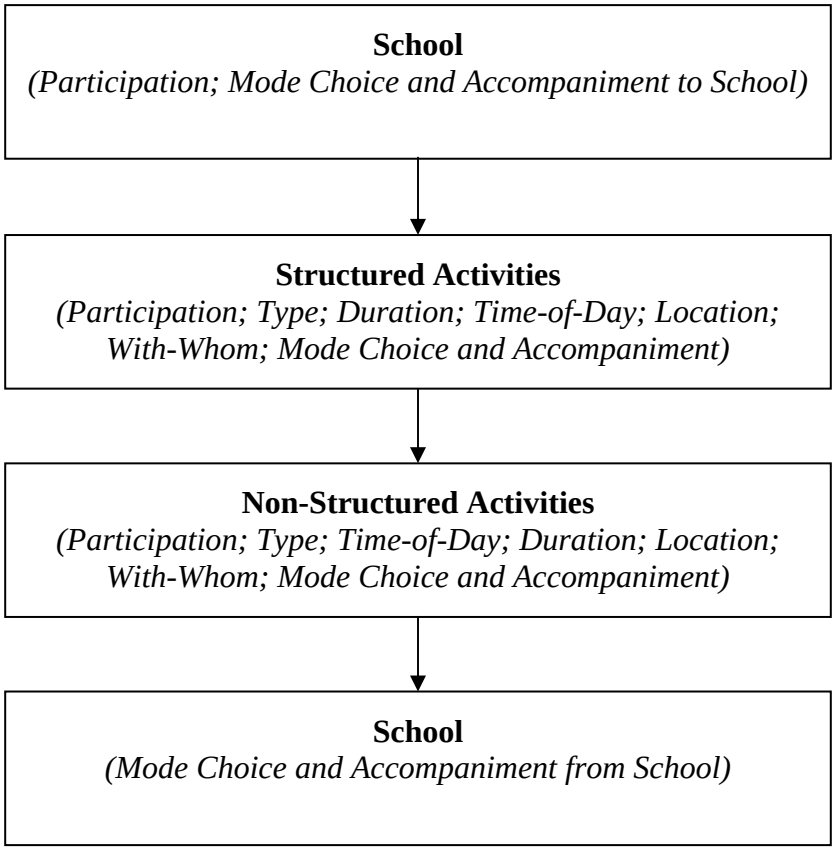

Figure 1. Hierarchical Process of Children's Activity Generation and Scheduling

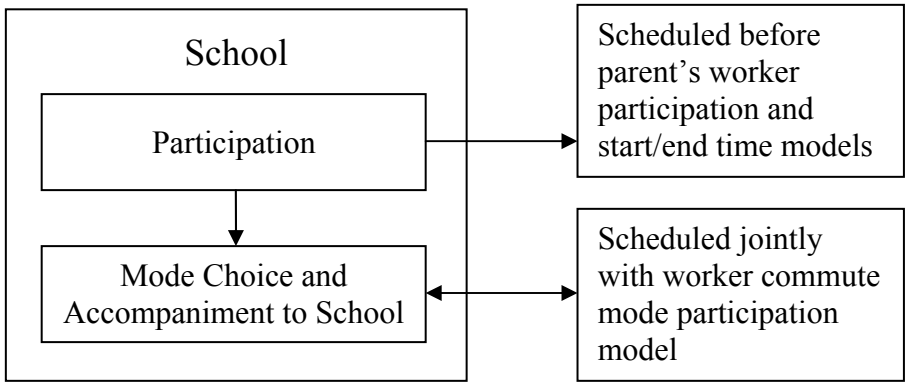

Figure 2. Generation and Scheduling of Children's School Activity

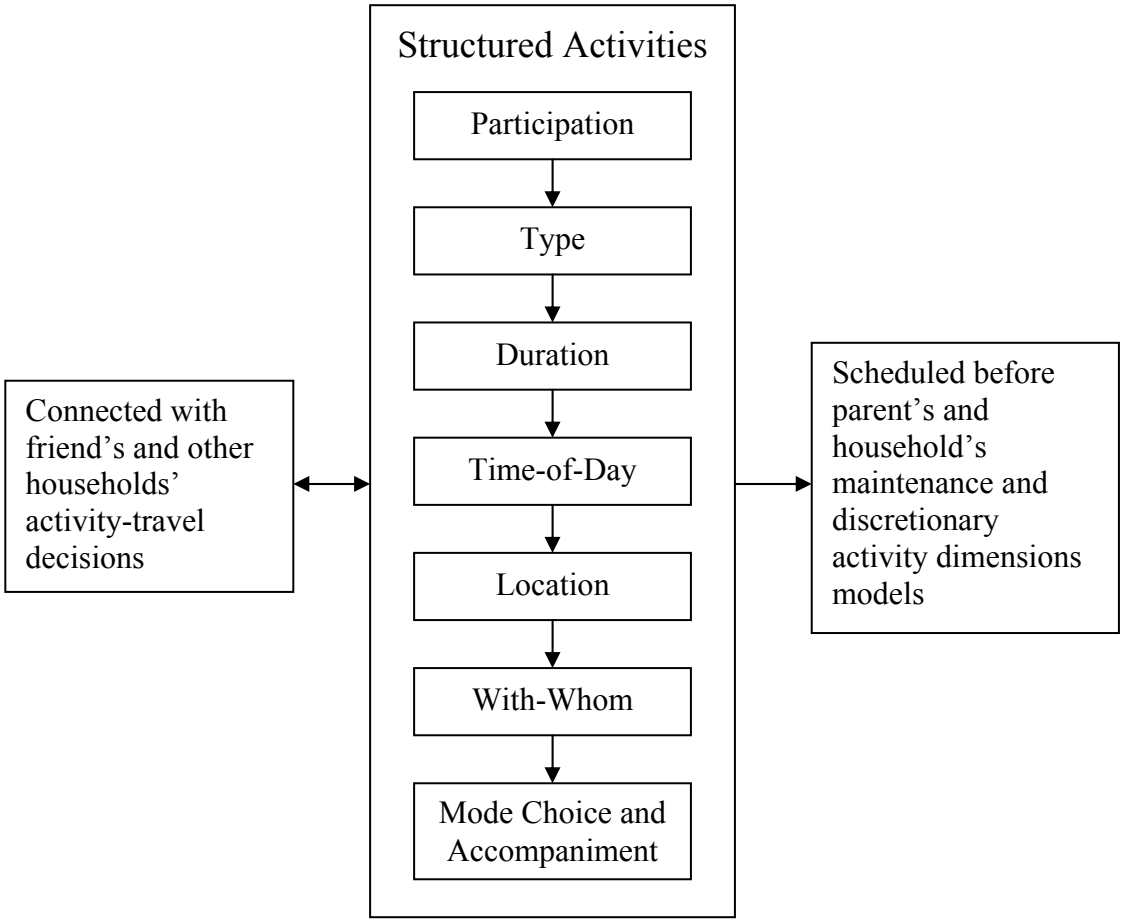

Figure 3. Structured Activities Generation and Scheduling

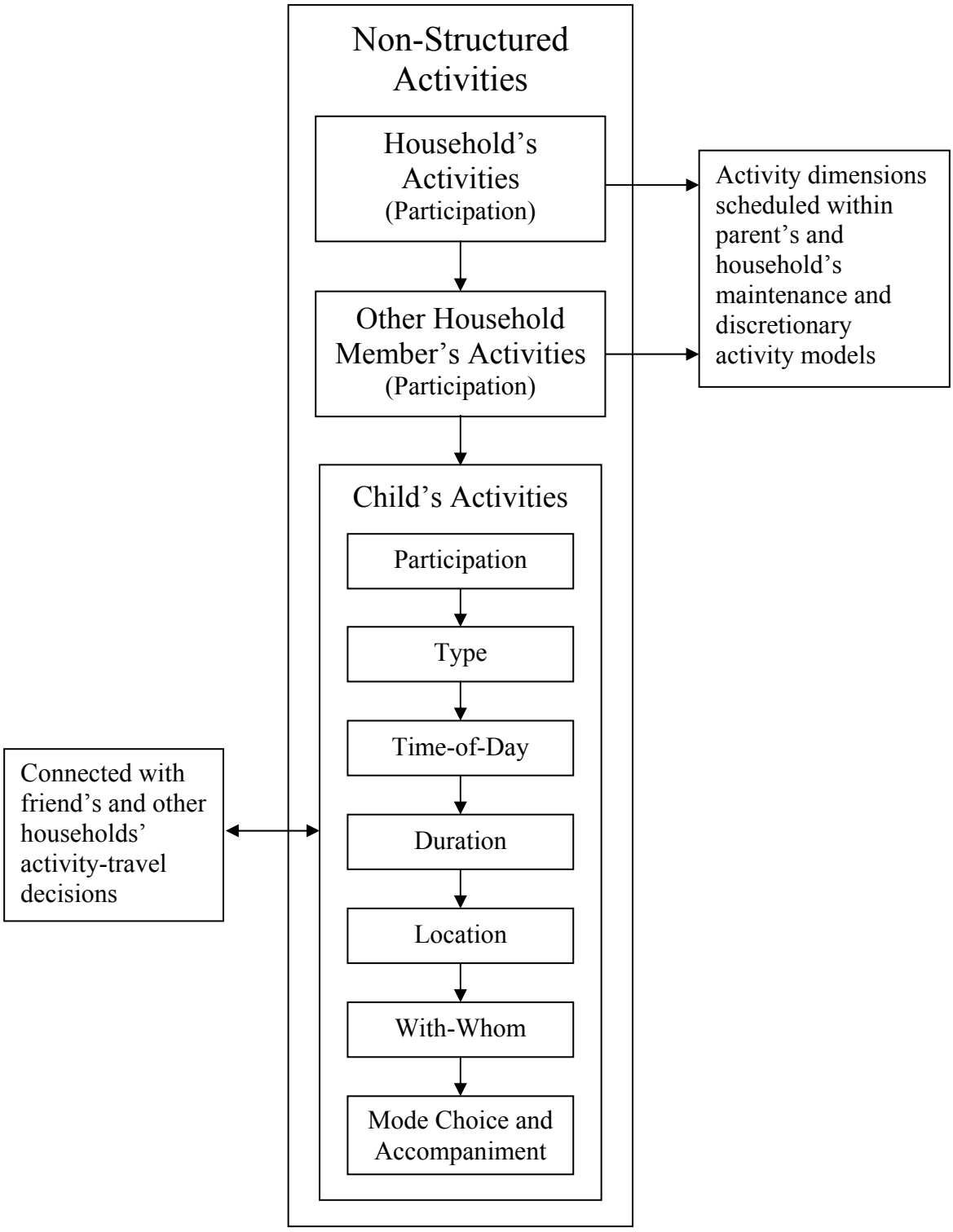

Figure 4. Non-Structured Activities Generation and Scheduling