The impact of time-space prism accessibility on time allocation and its propagation through intra-household interaction

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Introduction

Accessibility, a fundamental determinant of travel behavior and a key link with land use polcies, has been defined in many ways but generally it is a measure of an individual's freedom to participate in activities in the environment (Weibull 1980). Accessibility has been theorized as an important factor that impacts people's short to long-term behaviors. The significance of the relationship between accessibility measures and different types of behaviors has been studied in detail and two relevant studies to the methods here are Kitamura et al (2001),Lee et al (2009), and in the review by Handy (1996). However, with very few exceptions including the paper by Lee et al (2009), the accessibility measures that were used in past research are typically location-based accessibility measures that are measured using home or work as the anchor points. From the perspective of activity-based approaches, location-based accessibility measures are not sufficient to take into account the activity opportunities that a person experiences throughout a day. When multi-purpose trips and trip chaining are considered, we need accessibility measures that describe the opportunity each individual faces as this individual moves in the environment.

To accomplish this, accessibility measurement based on time geography has been considered to be a good alternative to the location-based accessibility measurement. Time geography is a constraint-based approach about temporal and spatial dimensions of individual behaviors. Based on the reasoning of time geography, the area that is within an individual's potential access can be delineated when a time budget and spatial constraints are given (Hägerstrand 1970, Kwan 1998, Miller 1991). This area is called potential path area (PPA) and time-space prism accessibility for an individual during a given time budget can be measured within the PPA.

In this paper, time-space prism accessibility measures are used to explain individual time use and a framework considering intra-household interaction is used for modeling behavior. The intra-household interaction framework provides a good opportunity to test the role of accessibility on bargaining on time use and task allocation in households as well as on activity participation behavior. This framework also offers an opportunity to trace changes in the role of accessibility in the time use interaction patterns as households progress from one life cycle stage to the next.

To model intra-household interaction, several different strategies have been used in travel behavior research. They include structural equations models (SEM; Golob and McNally 1996), structural discrete choice models (Gliebe and Koppelman, 2005), genetic algorithms (Meister et al, 2005), household utility maximization (Zhang et al. 2002, Srinivasan and Athuru 2005, Srinivasan and Bhat 2005, Bradley and Vovsha, 2005) and latent class cluster analysis (Goulias and Henson 2006).

We use SEM to build an easily expandable time use model and account for the endogeneity of time-space prism accessibility, which will be discussed in the model specification section.

Data and Models

This study used the California Statewide Travel Survey, conducted in the years 2000 and 2001, a set of very detailed network data (Dynamap/Transportation produced by Tele Atlas), and employment data from the US census 2000 summarized in block group units. The survey sample, consisting of 17,040 households and 40,146 individuals, 4,830 couple-head households without children and 1,411 couple-head households with one child that reported a complete 24-hour travel diary for each person were selected as the sample to assess the difference of the impact of accessibility between different household

life cycle stages. Nine distinct life cycle stages were defined from the selection and the definitions of them are given in Table 1.

The network data we used for this paper includes: type of road network, segment length, and speed limit for each segment, turn restriction(s), and one-way street enabling realistic modeling of travel environments. The total length of each network type in time-space prism serves as one type of the accessibility measure used in this study. The number of employees collected for each block group according to the North American Industry Classification System is considered as proxies of activity opportunity existing in the block group. However, in this analysis rather than the number of employees for each industry type, the total number of employees was used as an accessibility measure to provide a proxy for the overall relative amount of activity opportunity for different types of activities.

Table 1. Life cycle stages definition

Household composition	Both heads' ages	Group name	Group size
Couples without a child			
Only male head employed	-44	2M_1	183
	45-64	2M_2	359
Both heads employed	-44	2B_1	578
	45-64	2B_2	885
Retired couple	65-74	R_1	493
	75-	R_2	356
Couples with one child			
Only male head employed	-64	3M	340
Both heads employed	-44	3B_1	323
	45-64	3B_2	361

In order to measure time-space prism accessibility, the fixed portions of time-space path of each individual were identified using the activity types. The types of activities considered as spatially and temporally fixed are: home activities, work/school activities, medical appointment, community meetings, political or civic event, public hearing, voting, etc, and religious activities, traveling by intercity bus or airplane and any other types of activities that occurred at important activity pegs such at home, work or school. These activities are called skeletal activities.

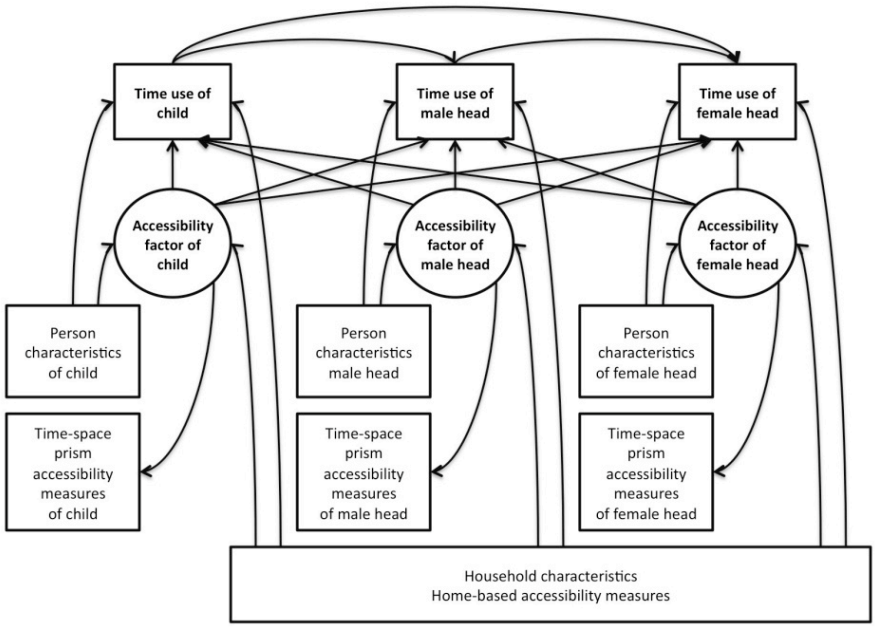
Then, the time budget between two temporally neighboring skeletal activities and the locations of the skeletal activities were used as the input for individual accessibility computation to delineate PPA. We used Network Analyst extension of ArcGIS for the computation. Accessibility indicators (number of employees and segment length of different types of network in this paper) are enumerated within each PPA as proxies for relative amount of activity opportunity or network infrastructure available. The accessibility measures were summed for each individual.

This paper uses the SEM framework that was defined for couples without a child in a previous paper of the same authors (Yoon and Goulias, 2009) and expand it for both couples without a child and couples with a child. In the previous paper, different activity priority and person priority settings in structural equation model were tested and different priority settings showed no difference in fit. Thus, we chose the order of (1) independent activity - (2) shared activity - (3) purchasing activity - (4) picking-up/dropping-off activity – (5) trip, and (1) child - (2) male head - (3) female head among the non-inferior activity priority settings and person priority settings.

We also tested different treatment of time-space prism accessibility measures. Especially the endogeneity of time-space prism accessibility was tested with different treatments for the accessibility measures. Conceptually, it is quite obvious that there exists mutual dependency between time allocation and time-space prism accessibility. Persons with more flexibility in temporal schedule would experience more accessibility throughout the day, and possibly would participate in more activities, and people seeking more activity engagement expand their time-space accessibility. Therefore, it is conceptually logical to treat the time-space accessibility as an endogenous variable.

We tested different model structures to find an appropriate treatment for time-space prism accessibility measures and concluded that a model structure using a latent factor representing the general magnitude of accessibility, which is measured by the time-space accessibility measures and varies depending on the explanatory variables, provides a good model fit as well as a good explanation of behavior. As explanatory variables, we used individual and household characteristics and home-based accessibility measures. The model structure is shown in Figure 1 and applied for the nine life cycle stages defined in the data section.

Figure 1. SEM for couples with a child



Results and Discussion

In this paper, we concentrate on showing the impact of time-space prism accessibility on activity participation and its importance in the presence of the other explanatory variables. More detailed discussion about the model fit and model specification can be found in the authors' forthcoming papers (Yoon and Goulias, 2009 and 2010).

The impact of accessibility factors on time allocation is shown in Figure 2. We took 1/10 of the activity and trip duration in minutes to adjust the order of variation. Therefore, the impact of factors or exogenous variable has to be multiplied by 10 to be interpreted as positive or negative impact in minutes. For example, in A1 of Figure 2, one unit increase of accessibility factor of male head is associated with 10-15 minutes' increase of male head's independent activity.

The most prominent difference between couples without a child and couples with a child is that the impact of accessibility factor is much larger in couple-head households without a child. Especially, the impact of accessibility factors on independent activity of the same person is the largest along with the impact on trip duration when there is no child in households, but it doesn't have significant impact on independent activity duration when there is a child in the household (IND1 in A1 and B1, IND2 in A2 and B2).

In the households with a child, increased accessibility is rather highly associated with shared activities between household members than other types of activities. These association patterns show that gaining of accessibility serves different purposes depending on the existence of a child in the household.

Asymmetric bargaining of purchasing activity based on accessibility in households without a child is also noticeable. In A1, one unit increase of accessibility factor for male head is associated with relatively

small (about 2 minutes) increase of purchasing activity of male (2M_1, 2B_1, 2B_2, R_1, and R_2) or doesn't have significant impact on purchasing activity of male head (2M_2), but in A2, one unit increase of accessibility for female head is associated with relatively large (about 4-5 minutes) increase of purchasing activity of female head in all cases.

However, the impact on spouse/partner's purchasing activity is reversed. When male head faces increased accessibility, it is associated with relatively large decrease of female head's purchasing activity but when female head faces increased accessibility, it is associated with relatively small decrease or insignificant decrease of male's purchasing activity. The relationship between accessibility and each head's purchasing activity in the households with a child is similar to that for the households without a child, but compensation of purchasing activity between household heads is not significant in the households with a child.

It implies that households make changes in their bargaining patterns in time use over their transition in life cycle stages. Moreover, not only the time itself but also activity opportunity is an important factor that is considered in the bargaining.

Figure 2. Impact of space-time prism accessibility on time allocation

A. Couples without a child

A1. Impact of male head's accessibility on time allocation

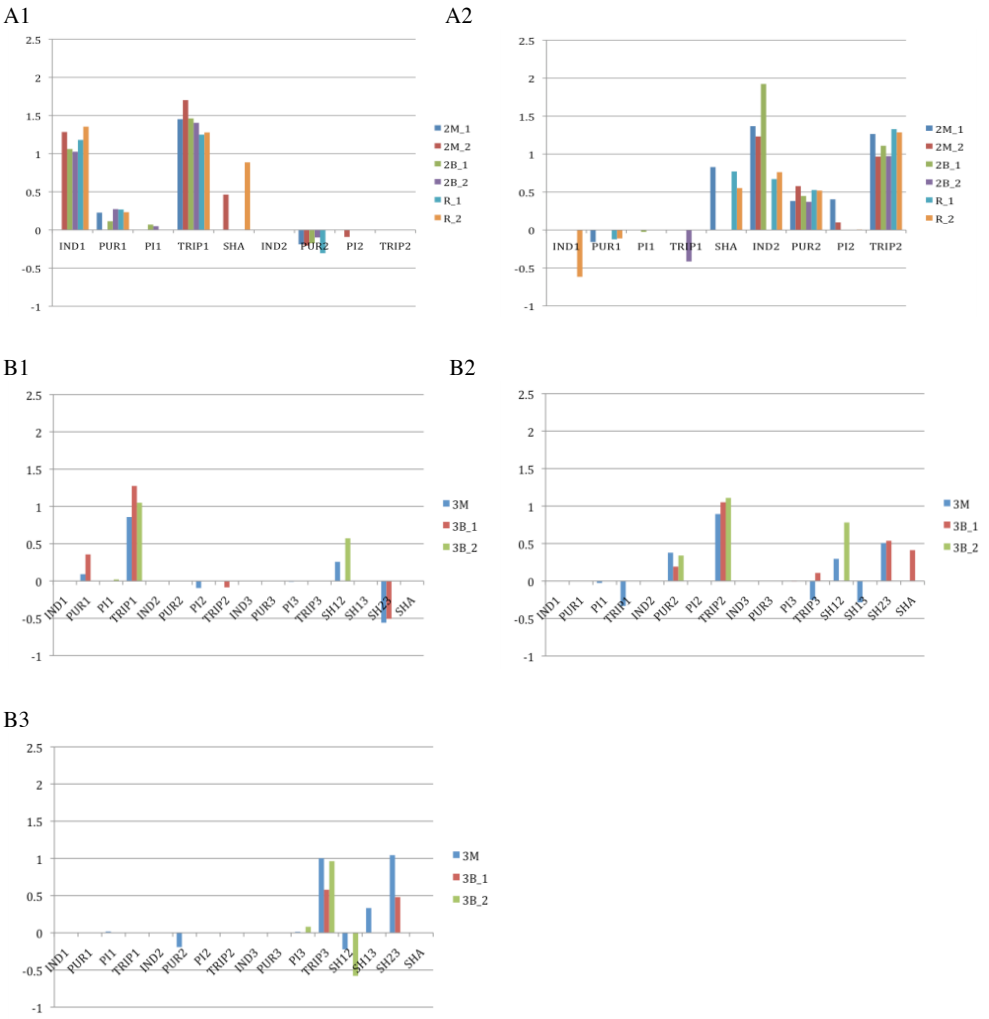
A2. Impact of female head's accessibility on time allocation

B. Couples with a child

B1. Impact of male head's accessibility on time allocation

B2. Impact of female head's accessibility on time allocation

B3. Impact of child's accessibility on time allocation



IND1, IND2, IND3: time allocated for independent activity of male head, female head and child respectively

PUR1, PUR2, PUR3: time allocated for purchasing activity

PI1, PI2, PI3: time allocated for picking-up/dropping-off

TRIP1, TRIP2, TRIP3: trip duration

SH12: activity duration shared between male and female heads

SH13: activity duration shared between male head and child

SH23: activity duration shared between female head and child

SHA: activity duration shared by all household members

This paper offers a time use model that includes individual spatio-temporal constraints, life cycle stage, land use and network infrastructure within an intra-household interaction framework. The result of the time use interaction models show that there exists individual and group heterogeneity in the patterns of time allocation, impact of accessibility on time allocation, and intra-household bargaining of time use. Accessibility plays a very interesting role in household decision making on time allocation. People interact not only based on the actual time allocation of each other but also based on the accessibility each person faces, in other words the level of potential to allocate time to certain types of activity. It implies that land use policies to increase density and the spatial distribution of opportunities will have very different impacts on person in households of different life cycle stage. In our analysis, having a child actually changes the relationship with the environment and makes people respond to the environment differently. In households with children, children "dictate" parents' schedule and constrain the impact of accessibility on parents' time use. It also implies totally different destination choice patterns depending on existence of children (and possibly composition/combination) in households

In addition, a more detailed multimodal network with the varying level of service offered depending on time and more descriptive information about activity opportunity would bring more realism to the model and benefit in using this framework to develop a regional application.

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