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Constraint-based assessment of intra-household bargaining on time allocation to activities and travel using individual accessibility measures

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ABSTRACT
Accessibility plays an important role in behavioral decision making. It influences a variety of behavior patterns in time use, resource allocation, and activity allocation of household members. In spite of the recognition of the importance of accessibility in behavioral modeling, appropriate accessibility measures based on time geography are rarely used in time use and activity participation models. This study aims to include accessibility measures in behavioral models and to assess the relationship between accessibility and time use, especially in the context of interaction within households. Accessibility measures based on time geography account for the temporal fixity and spatial settings around important activity pegs for each individual, and therefore provide a unique opportunity to assess temporal and spatial aspects of human behavior. In the analysis reported in this paper Structural Equation Model (SEM) is used to model the complex correlation between individual accessibility and time use and to explain individual and household heterogeneity. We address how accessibility measures has to be treated in behavioral models with different SEM model settings and report the intra-household interaction patterns in time allocation and the importance of individual accessibility in clarifying the impact of land use on travel behavior.

Keywords: Accessibility, time allocation, intra-household interaction, structural equation model

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1. INTRODUCTION

Human interaction is one of the most important topics in understanding of human behavior and travel behavior is not an exception in this statement. There have been many researches in transportation which were devoted on the studies of human interaction. As an example, the journal *Transportation* published a special issue about human interaction in 2005 (Bhat and Pendyala, 2005; Bradley and Vovsha, 2005; Gliebe Koppleman, 2005; Srinivasan and Athuru, 2005; Srinivasan and Bhat, 2005). The bottom line of the interaction studies is that an individual never behaves like a lone grain and the interaction between individuals is even stronger between household members. As the result, temporal scheduling and spatial organization of time-space path are interwoven between household members (Kostyniuk and Kitamura, 1982). An important family of approaches to study this intra-household interaction is based on the mechanism of bargaining in time and activity allocation between household members.

Bargaining and group decision making in households on activity participation considers many factors such as household resources (i.e., household income, number of vehicles, etc), individual and household needs (i.e., need for grocery shopping, need for earning income, need for supporting kids, etc), and individual characteristics (i.e., age, gender, education, employment status, etc). As the result of joint consideration of all the factors that influence decision making, we see the activity and time allocation patterns of households. Besides the factors listed above, whether someone has access to a certain type of activity opportunity is another important factor in making decisions on activity allocation. For example, as much as gender role has impact on allocating grocery shopping or taking care of school-going kids, having access for those activities has impact on bargaining between household members and allocating the activities. However, activity opportunity that is available to each household member hasn't been properly addressed in household decision making models using individual measures of accessibility.

In the lineage of our accessibility study, our previous paper (Yoon, Golob, and Goulias, 2009) analyzed travel behavior patterns of households in the state of California using home-based accessibility indicators as explanatory variables. In that analysis, we found that the impact of home-based accessibility on household behavior is significant, the level of impact varies by the type of behavior and the impact is different on different sub-groups of people. In this paper, we explore one level deeper into the behavior patterns by going down to the individual level and addressing the entire daily schedule of activities. Instead of applying unitary accessibility indicators measured based on home location alone, we use accessibility measures based on the spatio-temporal constraints of each individual.

In this paper, we test the feasibility of measuring individual accessibility and including them in travel behavior model. We also suggest a household interaction model on time use with individual accessibility measure and report significance of individual accessibility in explaining household decision making on time use. In this way, it is possible to test the impact of the built environment on travel behavior in a more complete context by considering propagation of accessibility impacts through human interaction.

In the following sections, we explain the quantification method for accessibility and the econometric models that we built.

2. LITERATURE REVIEW: *Place-based accessibility and individual accessibility*

Many different types of measures have been suggested and used to describe level of accessibility, but they can be classified into two large groups. One focuses on accessibility to activity opportunities from a location and the other focuses on accessibility to activity opportunities of an individual (Miller, 2005). Traditionally the former, place-based accessibility is defined using two elements: a transportation or impedance element and an activity element (Burns, 1979; Koenig, 1980). The transportation element describes how easy or difficult it is to travel between locations. Travel time and travel distance are the variables which are often measured as the impedance inflicted by the transportation system. The activity element describes how attractive a location is as a trip destination. There are many different place-based accessibility measures (i.e., distance measures, cumulative opportunity measures, gravity measures, and utility-based measures) but they share these two elements in their definitions.

While place-based accessibility measures the activity opportunities that can be reached from a location and for a given location it is usually assumed to be constant in a day, individual accessibility focuses on the activity opportunities that can be reached by an individual when his/her dynamic activity schedule is considered. In this sense, individual-based accessibility is defined using one more element, which is individual daily activity program. Time geography and its measurement theories describe how the space within an individual's potential reach with a given time budget can be delineated and how individual accessibility is measured based on the daily activity program of each individual (Hägerstrand, 1970; Kwan, 1998; Miller, 1991).

Time geography explains individual activity patterns based on spatio-temporal constraints. If we look at daily activity/travel patterns of an individual, activity locations and scheduling are not only affected by the locations of important pegs in a person's schedule (i.e., home/work/school location) but also constrained by the timing of the mandatory activities and the time budgets he/she can afford. The theoretical background of looking at activity footprints of an individual to explain behavior can also be found in the anchor point theory (Golledge, 1984) of behavioral geography. This perspective describes how an individual's activities are organized within a constrained space around anchor points (the important pegs mentioned above) and how the activity patterns can be explained behaviorally. In order to account for the conditions for behavioral decisions of each individual, a temporal component should be considered in measuring accessibility as well as the locations of activity pegs and this makes individual-based approaches completely different from place-based approaches. According to the time geography theories, the same location but at different times in a day will offer different accessibility depending on the time constraints a person faces.

Figure 1 briefly describes how individual-based accessibility is measured in this paper based on the locations of important pegs and time budgets in daily schedule. *A* in Figure 1 shows the space-time path of an individual during one day, and *B* shows two different types of accessibility measures. In *B*, [a] and [b] are based on spatio-temporal constraints of the individual, and [c] and [d] show conventional place-based accessibility measures. [a] and [b] capture the complete set of opportunities accessible to the individual and also show the variation of accessibility in accordance with the time budget between two fixed activities while [c] and [b] are not able to do that.

3. DATA USED

The California Statewide Travel Survey, conducted over several months in the years 2000 and 2001, provides an excellent starting point for disentangling the relationships between space, infrastructure, and sociodemographics. The survey sample, consisting of 17,040 households and 40,146 individuals, is a quota sample by county and planning region, rather than a representative sample of California proportional to the population of each county. Most of the trip destinations in the survey have been geocoded so that the trip destinations can be overlaid with the other two geographic data sets in Geographic Information Systems for further computation and analyses. Among the 17,040 households, 4,830 couple-head households without children which reported a complete 24-hour travel diary for each head were selected as a test bed to assess the feasibility of this approach. Selection of specific type of households constrains the type of intra-household interaction existing between household members and therefore all the possible interactions can be enumerated and controlled in the model.

The network data we used for this paper (Dynamap/Transportation by Tele Atlas) has very detailed information on the road network across California State. It includes type of road network, segment length, and speed limit for each segment, turn restriction, and one way street enabling realistic modeling of travel environments. The types of road network included in the data set are primary roads with limited access (type 1), primary roads without limited access (type 2), secondary/connecting roads (type 3), and local/ neighborhood/rural road (type 4), but any information on public transportation network is not included. The total length of each network type in time-space prism would serve as a measure of accessibility. The detail of measurement process will be explained in the next section.

The state of California is divided into 22,133 zones using the US Census 2000 block groups. The number of employees collected for each block group according to the North American Industry Classification System (NAICS) is used as proxies of activity opportunity existing in the block group. The NAICS classifies industries into fourteen types and the number of employees for each of them represents the relative amount of opportunity to participate in the related type of accessibility (i.e., the number of employees in retail industry represents the opportunity to participate in shopping activities). However, in this paper 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 activity types.

4. MEASUREMENT OF INDIVIDUAL ACCESSIBILITY USING GEOGRAPHIC INFORMATION SYSTEM (GIS)

The activities that are fixed spatially and/or temporally and constrain space time path are called skeletal activities. Table 1 shows how the 4,830 households' time allocation is constrained by the skeletal activities. Males reported 20,941 activities and females 20,605 in total and almost half of them were home activities. Home activities were considered as skeletal considering the nature of the activities occurring at home such as sleeping, eating, being with family or household chores which happens usually at fixed time and very strictly at home. The four activity types listed after home activities (work/school activities, medical appointment, community meetings, political or civic event, public hearing, voting, etc, and religious activities) were considered as spatially and temporally fixed activities. The activity location and time for these activities are not usually decided by the individuals, but determined by an external entity. Traveling by intercity bus or airplane also was considered as a type of skeletal activities considering their fixed schedule. Their boarding and landing schedule constrain an individual's activity location and schedule for the rest of the day. The last constraint type 'other locational reason' was included because of its activity location. It represents any type of activities that occurred at important activity pegs such at home, work or school (e.g., waiting for bus at work location or getting picked up at school.) Among 22,124 out-of-home activities reported by the sample of 9,660 people, 7,697 activities were considered spatially and temporally fixed according to the classification rules explained above and the rest 14,427 activities were considered as being pursued within the time-space prism.

As the first step of individual accessibility measurement, the time budget between two temporally neighboring skeletal activities and the locations of the skeletal activities were extracted as the input for individual accessibility computation. Second, from the input data prepared from activity diaries, network-based potential path area (PPA) was computed using Network Analyst extension of ArcGIS. PPA is the area where a person can potentially pursue activities within the time budget while they are traveling from one skeletal activity location to the next skeletal activity location. 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.

Then each accessibility measure was summed for each household head. This implies that when an individual can access an activity location twice a day, for example once during AM commute and once during PM commute, the activity opportunity is counted twice. This strategy can also be modified to count distinct opportunities only once during a day.

We use a few assumptions to simplify the measurement procedure and they are:

- travel time between two locations is symmetric
- every travel episode is made at the speed limit of each road segment, and
- travel mode is driving a private car in all the cases.

To make the measurement more realistic, other strategies such as realistic travel time, facility opening hours (Weber and Kwan, 2002), or minimum activity duration (Kim and Kwan, 2003) may be used.

5. MODELING WITH STRUCTURAL EQUATIONS

5.1 Structural equation with/without factors and measurement

Structural equation model (SEM) has strength in modeling interaction and causal relationship between variables. SEM has been used to take into account for the intra-household interaction in activity participation in travel (i.e., Golob and McNally, 1997). The result from SEM is informative in that it provides directional direct and indirect effects between endogenous variables. It is also possible to use different types of travel behavior variables as endogenous variables together. The standard structural equations model (with only observed variables, without latent variables) is formulated as (1)

$$y = By + \Gamma x + \zeta \qquad (1)$$

where

y is p x 1 column vector of observed endogenous variables,

x is q x 1 column vector of observed exogenous variables,

B is p x p coefficient matrix of causal links between the m endogenous variables, and

Γ is p x q coefficient matrix of direct causal (regression) effects of the exogenous variables on the endogenous variables.

When we have latent endogenous and exogenous variable, the equation is formulated as (2).

$$\eta = B\eta + \Gamma\xi + \zeta \qquad (2)$$

where

η is m x 1 column vector of latent endogenous variables,

ξ is n x 1 column vector of latent exogenous variables,

B is m x m coefficient matrix of causal links between the m endogenous latent variables, and

Γ is m x n coefficient matrix of direct causal (regression) effects of the exogenous variables on the m endogenous variables.

ζ is the disturbance vector, which is uncorrelated with ξ and $E(\zeta)=0$

A MIMIC model can be a variant of SEM when we consider *Multiple Indicators and MutIple Causes* of single latent variable. In this study we measured five different accessibility indicators for a latent accessibility factor and they are the indicators in the MIMIC model. Then again, the latent accessibility factor varies depending on multiple (measured) exogenous variables. This model design leads to the equations below (3).

$$\eta = B\eta + \Gamma\xi + \zeta \qquad (3)$$
$$y = \Lambda\eta + \epsilon$$
$$x = \xi$$

y is p x 1 column vector of observed time use and accessibility variables,

x is q x 1 column vector of observed exogenous variables,

η is m x 1 column vector of latent endogenous variables for time use and accessibility,

ξ is n x 1 column vector of latent exogenous variables (in this model holds $x = \xi$),

Λ is p x m coefficient matrix of the relation of y to η

ε is p x 1 error term of y

Using SEM, causal effects of individual/household characteristics and especially accessibility measures on time use variables and endogenous causal effect between time use variables are assessed. Modeling with latent variables is advantageous in this case because it allows to account for the abstract entities that people consider in their decision making process.

5.2 Modeling time use during a fixed time window

Modeling of time use during a day (24 hours) brings up an analytical issue in using structural equation. When we do not allow for measurement error in travel diaries the sum of time use for each individual is 24 hours. This constant total makes a part of the covariance matrix of a model singular, thus making the whole covariance matrix singular whatever variable is added to the time use variables.

Let's assume that we use n types of activities for time use modeling, and then equation (4) holds for every observation.

$$\sum_{i-1}^{n} h_i = 24 hours \tag{4}$$

where
h_i is time allocated to activity type i (including trips)

Let $\mathrm{h} = (\mathrm{h}_1, \mathrm{h}_2, \dots, \mathrm{h}_n)$. (5)

Then

$$\mathrm{COV}(\mathrm{h}) = \begin{bmatrix} \mathrm{var}(\mathrm{h}_1) & \mathrm{cov}(\mathrm{h}_1, \mathrm{h}_2) & \cdots & \mathrm{cov}(\mathrm{h}_1, \mathrm{h}_n) \\ \mathrm{cov}(\mathrm{h}_2, \mathrm{h}_1) & \mathrm{var}(\mathrm{h}_1) & \dots & \mathrm{cov}(\mathrm{h}_2, \mathrm{h}_n) \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{cov}(\mathrm{h}_n, \mathrm{h}_1) & \mathrm{cov}(\mathrm{h}_n, \mathrm{h}_2) & \cdots & \mathrm{var}(\mathrm{h}_n) \end{bmatrix} \tag{6}$$

By the constant sum of the time use variables, holds the equation below.

$$\begin{aligned} \mathrm{cov}(\mathrm{h}_j, \mathrm{h}_k) &= \mathrm{cov}\left(24 - \textstyle\sum_{i \neq j} \mathrm{h}_i , \mathrm{h}_k\right) \\ &= -\textstyle\sum_{i \neq j} \mathrm{cov}(\mathrm{h}_i, \mathrm{h}_k) \end{aligned} \tag{7}$$

Then one of the columns (or rows) can be represented with a linear combination of the other columns (or rows), which means the covariance matrix is singular. When a sub-matrix of a matrix is singular, the whole matrix becomes singular. When we have time use variables that sum up to 24 hours (or other constants), the covariance matrix of the whole structural equation becomes singular (not invertible). This makes it impossible to estimate the structural equation model. To avoid this problem, we excluded home activities and focused just on out-of home activities and trips. Home activities are considered as the time left after allocating time for the other activities.

5.3 Accessibility as exogenous variable

First analysis on the relationship between accessibility and time use considers accessibility measures as exogenous variables. It means that the accessibility is given for each person as predetermined condition for the day based on the spatio-temporally fixed activities. Individuals choose activity schedule considering the accessibility condition and the structural equation model captures the impact of individual accessibility on time use controlling for socio-economic characteristics of households and individuals. The intra-household interaction in time use is also considered in a recursive manner. Figure 2-A shows the overall structure of this model.

5.4 Accessibility as endogenous variable

Another way to account for accessibility in time use model is considering it as an endogenous variable. Gaining accessibility is highly dependent on available time budget and time allocation to different activities depends on the amount of accessibility gained. This inter-dependent relationship between accessibility and time use varies depending on who the person is and what circumstances the person faces. Using accessibility as an endogenous variable, it is possible to study the impact of individual and household characteristics on gaining accessibility. Figure 2-B shows the overall structure of this model. This model setting enables modeling who gains more accessibility and which type of activity is accommodated by the accessibility. Accessibility from home and work location may be included in the model and it is equivalent to the inclusion of longer term decision such as location choice for home and work location in the activity-travel model system.

6. ANALYSIS

The 4,830 couple-head households without children were classified into four groups based on each head's employment status with the assumption that wage earning activity brings much difference in individual time allocation mechanism, and bargaining power influencing the assignment of a specific role to each head. The sample size of each group is listed below:

1) Household group 1: Neither of two heads working	1,791
2) Household group 2: Only male head working	782
3) Household group 3: Only female head working	431
4) Household group 4: Both heads working	1,826

Different model structures were tested for the four groups and the purpose of group-wise analysis is to verify different interaction patterns with different household compositions.

6.1 Path analysis with activities and trips with different activity priority and gender priority settings

In this section, activity priority in individual time allocation and gender priority in group-wise time allocation is tested. Activities were classified as home, independent, allocated and shared activities according to the activity classification rule of household interaction study by Zhang et al. (2002), and then allocated activities were classified one step further as purchasing activities and picking up/dropping off someone expecting the activity opportunities and network infrastructure would have different impact on the two activity types. For shared activities, even partially shared activities were counted and the shared activity duration is included as the time allocated on shared activity. The SEM modeling follows the assumptions of activity-based model. Activities were considered as the driving force of trips and they were placed before trips in the path analysis and further structural equation models were estimated based on that.

To test activity priority order among activities and to determine the structure between time use variables in SEM models, four different activity priority settings were tested with recursive path analysis. The priority order settings are:

1) Independent - Shared - Allocated (Purchasing - Picking up/Dropping off) - Trip
2) Independent - Shared - Allocated (Picking up/Dropping off - Purchasing) - Trip
3) Shared - Independent - Allocated (Picking up/Dropping off - Purchasing) - Trip, and
4) Allocated (Purchasing - Picking up/Dropping off) - Independent - Shared - Trip

In the recursive path analysis, activities of higher priority have direct impact on the activities of lower priority. For example, in the first case, independent activities have direct impact on all the other types of activities and trips, and shared activities have direct impact only on allocated activities and trips. According to the same rule, allocated activities have direct impact only on trips.

Each of the activity priority settings is tested for male-priority and female-priority settings to see if there is clear leading of a gender in time allocation. Each activity type of the gender of priority has direct impact on the counterpart of the other gender. For example, when female has priority in the household, independent activity of female has direct impact on independent activity of male, allocated activity of female has direct impact on allocated activity of male, and so on. Between different types of activities of the two heads, an activity of higher priority of one head has direct impact on the activities of lower priority of the other head.

The model fit of the 8 settings is given in Table 2. Different settings of activity priority and gender priority do not bring significant difference in model fit. This is an expected result in that estimation of structural equation depends on covariance matrix of variables. It implies that the relation between time use of two household heads is more joint arrangement or equally mutual interaction rather than clear causality.

After these experiments of specification we can assign activity and gender priority settings without violating implicit causality in the data. We chose the first activity priority setting with male priority for convenience.

6.2 Structural equation models with accessibility and explanatory variables: comparison of model fit with different treatment of accessibility measures

Seven structural equation models were built using different treatments for accessibility variables to see how we have to use accessibility measures in the time use model. First the individuals who didn't make any trip were classified separately. According to the measurement method, the individuals who did not make any trips have zero individual accessibility; these people belong to the zero accessibility group. For the other individuals who made at least one trip, accessibility measures were treated in three different ways. One option is to divide accessibility into nine categories. This makes 10 categories including the zero accessibility group (setting A1). Another option is to divide accessibility into three categories and this makes four discrete categories including the zero accessibility group (setting A2) and the third treating accessibility as a continuous variable.

The accessibility measures are concentrated at zero because of the people who did not travel and its distribution is positively skewed with high degree. It has to be noted that it might be difficult to see the impact of accessibility measures because measurement values are concentrated in a narrow bracket compared to the whole range of accessibility measures (A3). To normalize the distribution of the measurement value, we took natural log of the accessibility measures for the fourth treatment (A4). As the fifth model setting, a latent factor is used to represent the level of accessibility for each household head. The natural log of accessibility measures that was used in the fourth setting serves as observed indicator variables for the accessibility factor (A5, A5' and A6).

For A1-A4, the accessibility measures are considered as exogenous variable, and for A5, A5' and A6 accessibility factors are considered as endogenous. In Table 3, the model fit of A2-A6 is presented for comparison. A1 didn't reach convergence due to its large number of dummy variables for accessibility measures and it is excluded from the discussion here.

First of all, it should be noted that none of the model versions was rejected in spite of their low p values. Chi-square is one of the sample size-dependent indices for model fit, and a large sample size generally makes chi-square higher compared to a smaller sample size for the same structural equation model (Tanaka, 1993). We are using a sample which is large enough to make the p value of any model very small. Therefore we didn't reject any of the models given in table 3. We also tested them on a randomly selected smaller sub-sample and verified that the model is actually significant leading to the same conclusions.

For relatively equally fitting models selection of a suitable model for interpretation should be based on a model's ability to help us understand more complex relationships and possible use in policy analysis. A2 shows the best model fit among the models that consider accessibility as an exogenous variable. It implies that the relation between time use and accessibility cannot be fully described with a simple linear regression of them. However, classifying accessibility level into four groups is simplifying the reality too much. It is problematic when we try to interpret the result in the real world because it ignores the heterogeneity of accessibility experienced by different individuals.

Between A3 and A4, A3 shows better fit than A4, however when latent accessibility factor is introduced, only the accessibility variable setting used for A4 brings convergence to the model. A5 column of Table 3 shows the model fit when the accessibility variables in A4 were used as observed measurement of latent accessibility factor (For A5, no correlations between variables or error terms were specified.). It shows a better model fit than A3 and A4 do.

For the sixth model (A5'), correlations were specified between two factors and between the error terms of the same type of time use variables and the same type of accessibility measures of the two heads in addition to the model specification of A5. A6 uses the same model structure as A5' but includes population density around home location and home accessibility to describe home location choice. As a proxy of home accessibility level, the number of employees accessible within 20min's travel from home location was measured.

6.3 Interpretation of coefficients

The total effect from the result of the last model (A6) is given in Table 4. As described in figure 2, there are three groups of variables in each table: endogenous variables (accessibility factors, activity duration and trip duration for each gender), accessibility indicators, and exogenous variables (household and individual characteristics). 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 but not the impact between activity and trip duration. For example, 0.013 on the Trip1 column of Table 4, the impact of one minute increase in independent activity of the male head, can be interpreted as 0.013 minutes increase on male head's trip. On the other hand, 2.395 on the same column, the impact of living in an area with second lowest percentile population density can be interpreted as 23.95 minutes increase of the male head's trip.

Measurement of accessibility factor

Measurement coefficients are given as relative ratio to the coefficients of the network type 1. The coefficients are all significant and very consistent across gender and household types. According to this result, it is possible to relate a level of accessibility to a certain amount of activity opportunity and network infrastructure in time-space prism for anyone. It means that the latent concept of accessibility is actually quantifiable and can be measured using appropriate measurement variables.

Accessibility factor and time use

Increase of one's own accessibility factor generally accommodates the person's activity and trip with an exceptional case of working male head of the 2nd group and non-working male head of the 3rd group. In this case, accessibility factor did not have a significant impact on independent activity. It means that the male head's time allocation on independent activity does not depend on the level of accessibility in the 2nd and 3rd group. On the other hand, for working female head of the 3rd group and non-working female head of the 2nd group accessibility has a significant impact on time allocation for independent activity. It suggests the time allocation mechanism of male and female is different when one of them is the only wage earning person in the household. The different magnitude of coefficients on activities and travel of different genders also shows asymmetrical impact of accessibility on activity and travel even when their employment status and their partner/spouse's employment are considered.

The coefficients between time use variables show the bargaining between different types of activities of an individual and between the two heads.

- Male head's independent activity has positive impact on female head's independent activity except for the 3rd group. It means when one of the two heads schedule independent activity, the other person is likely to allocate more time on independent activity.
- In the 2nd and 3rd group, where only one household head is working, only the wage earning household head's independent activity has negative impact on shared activity.
- Male heads of the 1st, 2nd, and 3rd group do not trade off their independent activity with purchasing activity. On the other hand females do not trade off their independent activity with purchasing activity when they are the only wage earning person in the household (3rd group).
- Independent activity has positive impact on the other person's purchasing activity except on the purchasing activity of females in the 3rd and 4th group where females work.
- In the 2nd and 3rd group, more purchasing activity of male heads is associated with less purchasing activity of female heads but in the 4th group, more purchasing activity of male heads is associated with more purchasing activity of female heads.

In addition to the bargaining between time allocations to different activity types, the bargaining based on accessibility is also noticeable. Depending on the employment status of each head, accessibility of each person has different impact on the other person's time allocation.

- The negative impact of male's gaining accessibility on female's independent activity is the highest in the second group, but it doesn't show up in the 3rd and 4th group where female works.
- The negative impact of male's gaining accessibility on female's purchasing activity is the highest in the first group, but it doesn't show up in the 3rd group where female is the only wage earning person in the household.
- Female's gaining accessibility does not have a significant impact on male's independent activity in any group.
- The negative impact of female's gaining accessibility on male's purchasing activity is significant only in the first group where either of them is not working.

In terms of bargaining based on accessibility, the third group shows very distinct interaction pattern. Male and female heads time allocation does not depend on each other's accessibility level and their time use is very independent of each other. It suggests that gender role and economic status of the heads has very important impact on their interaction patterns.

From the coefficients for exogenous variables, we can see how much impact they have on time allocation patterns and the accessibility level. It shows how the individual and household life style changes in terms of time allocation and accessibility depending on household and individual characteristics. Generally, higher home accessibility has positive impact on gaining individual accessibility for both gender except non-working females of the 2nd group, however its impact on activity participation or travel doesn't show clear patterns in any group. It implies that the impact of land use on travel behavior has to be addressed with consideration of spatial organization of activity locations and temporal constraints of each individual.

7. CONCLUSION

This paper suggests a time use model that encompasses individual spatio-temporal constraints, land use and network infrastructure within an intra-household interaction framework. Variables representing land use and network infrastructure available for each individual were measured based on individual spatio-temporal constraints in their schedule. This measurement method provides individual-specific measures unlike home-based or work-based accessibility measures. We found it feasible to measure individual accessibility based on spatial and temporal constraints reported in travel diaries for a large sample and to use the measures in behavior models.

The result of the time use interaction models shows that there exists individual heterogeneity and group heterogeneity in the patterns of time allocation, impact of accessibility on time allocation, and intra-household bargaining of time use. Accessibility shows 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, in other words the level of potential to allocate time to certain types of activity. It implies that people consider longer time span than one day, for which the survey data was collected, when they bargain on time use.

It suggests that consideration of interaction would reveal the impact of a policy on land use or network infrastructure with more complete picture of the whole system. With interaction framework and constraint-based individual accessibility measures, it was possible to consider need and desire of individuals and households to pursue a certain type of activities, spatio-temporal constraints of each individual, and the spatial distribution of activity opportunity and network infrastructure together.

As future work, the model framework used in this paper will be expanded to households with more household members and the interaction patterns will be analyzed according to the life course of households. In addition, a more detailed multimodal network with the level of service offered will also be used within this framework to develop a regional application.

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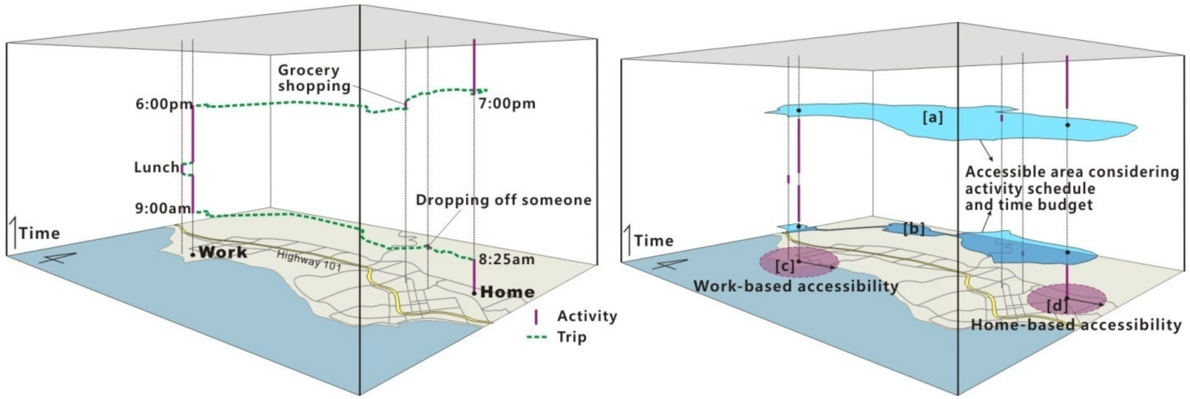
Figure 1. Accessibility measurement based on individual space-time path.

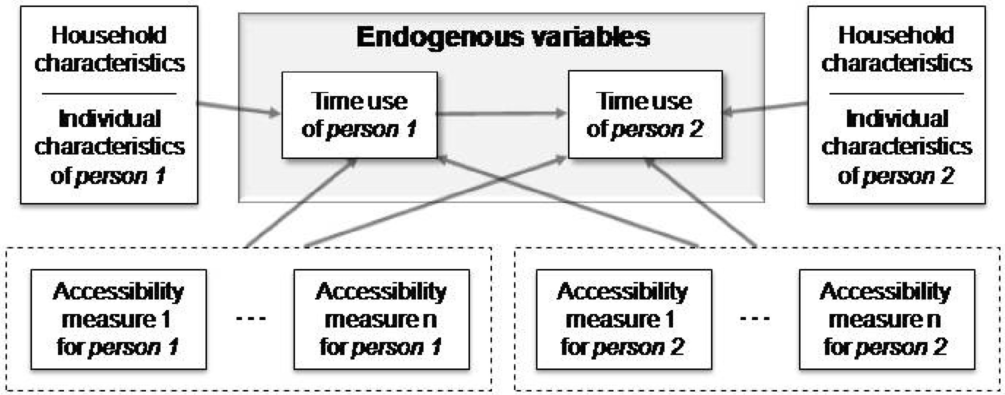
A. **B**.



A. Space-time path of an individual for a day.
B. Accessibility measures
[a, b] Accessibility measured based on activity schedule and time budget.
Time budget for [a]: 60 minutes, time budget for [b]: 35 minutes
[c, d] Accessibility measured from home and work location based on distance

Figure 2. Model structure

A



B

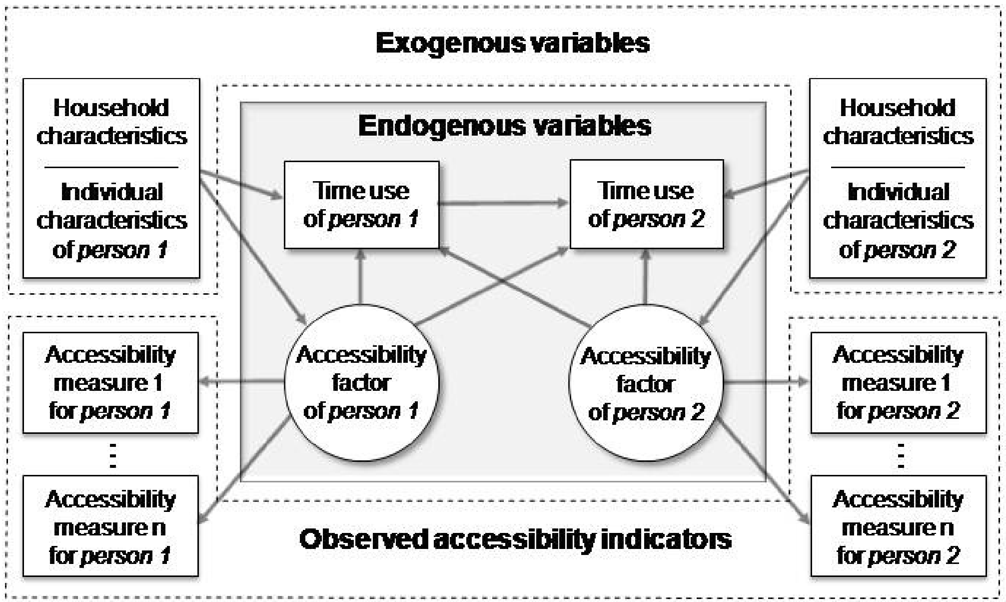


Table 1. Skeleton activities which constrains scheduling of the day (4830 couples without children)

	Total number of activities including home activities	Total number of skeleton activities	Home	Work/ School	Medical	Community meetings, political or civic event, public hearing, voting, etc	Church, temple, religious meeting	Traveling with fixed schedule (Intercity bus, Airplane)	Other locational reason
Male head	20941	14091	9791	3416	363	105	157	98	161
Female head	20605	13038	9641	2502	420	88	203	59	125

Table 2. Activity priority and gender priority in time allocation

Order of activity priority setting	Independent Shared Allocated (PUR-PICK) Trips		Independent Shared Allocated (PICK-PUR) Trips		Shared Independent Allocated (PUR-PICK) Trips		Allocated (PUR-PICK) Independent Shared Trips	
Gender priority setting	Male	Female	Male	Female	Male	Female	Male	Female
Chi-Square Test of Model Fit								
Value	68.472	68.472	68.226	69.223	69.223	68.472	67.842	68.001
Degrees of Freedom	32	32	32	32	32	32	32	32
P-Value	0.0002	0.0002	0.0002	0.0001	0.0001	0.0002	0.0002	0.0002
Chi-Square Test of Model Fit for the Baseline Model								
Value	3257.603	3257.603	3257.603	3257.603	3257.603	3257.603	3257.603	3257.603
Degrees of Freedom	144	144	144	144	144	144	144	144
P-Value	0	0	0	0	0	0	0	0
CFI/TLI								
CFI	0.988	0.988	0.988	0.988	0.988	0.988	0.988	0.988
TLI	0.947	0.947	0.948	0.946	0.946	0.947	0.948	0.948
Loglikelihood								
H0 Value	-140141	-140141	-140141	-140142	-140142	-140141	-140141	-140141
H1 Value	-140107	-140107	-140107	-140107	-140107	-140107	-140107	-140107
Information Criteria								
Number of Free Parameters	144	144	144	144	144	144	144	144
Akaike (AIC)	280571	280571	280571	280572	280572	280572	280571	280571
Bayesian (BIC)	281504	281504	281504	281505	281505	281504	281504	281504
Sample-Size Adjusted BIC (n* = (n + 2) / 24)	281047	281047	281047	281048	281048	281047	281046	281046
RMSEA (Root Mean Square Error Of Approximation)								
Estimate	0.031	0.031	0.031	0.031	0.031	0.031	0.03	0.031
90 Percent C.I	0.021	0.021	0.020	0.021	0.021	0.021	0.020	0.020
.	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
SRMR (Standardized Root Mean Square Residual)								
Value	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019

Table 3. Comparison of model fit with different accessibility variable settings

Accessibility variable setting	A2	A3	A4	A5	A5'	A6
Chi-Square Test of Model Fit						
Value	1827.918	1739.278	1952.505	20768.804	16003.716	16679.043
Degrees of Freedom	1224	976	976	3084	3058	3629
P-Value	0	0	0	0	0	0
Chi-Square Test of Model Fit for the Baseline Model						
Value	12439.792	9990.573	10500.597	150054.612	150054.612	153521.095
Degrees of Freedom	2844	2412	2412	4712	4712	6080
P-Value	0	0	0	0	0	0
CFI/TLI						
CFI	0.937	0.899	0.879	0.878	0.911	0.911
TLI	0.854	0.751	0.702	0.814	0.863	0.852
Loglikelihood						
H0 Value	-64204.992	-530014.006	-136030.005	-145438.155	-143055.611	-147199.908
H1 Value	-63291.033	-529144.367	-135053.753	-135053.753	-135053.753	-138860.387
Information Criteria						
Number of Free Parameters	1656	1472	1472	1704	1730	2527
Akaike (AIC)	131721.984	1062972.012	275004.01	294284.309	289571.221	299453.817
Bayesian (BIC)	142457.173	1072514.402	284546.4	305330.663	300786.123	315830.114
Sample-Size Adjusted BIC (n* = (n + 2) / 24)	137195.001	1067836.916	279868.914	299915.965	295288.806	307800.221
RMSEA						
Estimate	0.02	0.025	0.029	0.069	0.059	0.055
90 Percent C.I.	0.018 0.022	0.023 0.027	0.027 0.031	0.068 0.070	0.058 0.060	0.054 0.055
SRMR						
Value	0.008	0.009	0.009	0.055	0.014	0.012

The degrees of freedom of the baseline model is calculated as the sum of the number of elements in the lower triangle of covariance matrix of y and the number of elements of covariance matrix of x and y. For example, A3-A5 and A5' have the same number of variables (72) but the difference in the number of x and y variables makes their degrees of freedom different (p=9 and q=63 for A3 and A4, and p=19 and q=53 for A5 and A5'). For A3 and A4, the degrees of freedom for the baseline model is calculated as (9-1)*9/2+9*63=2412, and for A5 and A5' as (19-1)*19/2+19*53=4712.

Table 4. Model coefficients for the 4th group (Working male and working female) with A6 model setting

		F1	F2	IND1	PUR1	PICK1	TRIP1	SHR	IND2	PUR2	PICK2	TRIP2
Endogenous variable												
Accessibility factor (Male)	F1			1.029	0.228	0.06	1.488	0.394		-0.14		
Accessibility factor (Female)	F2						-0.246	0.295	1.206	0.393	0.045	1.125
Male time use												
Independent	IND1				-0.008		0.013	-0.174	0.7			
Purchasing	PUR1						0.143			1.893		
Picking up/dropping off	PICK1											
Trip	TRIP1											
Shared activity	SHR				-0.013		0.04			-0.025		0.059
Female time use												
Independent	IND2				0.016			-0.103		-0.024		0.022
Purchasing	PUR2											
Picking up/dropping off	PICK2											0.18
Trip	TRIP2											
Measurement variable												
Accessibility measurement for male												
Network type 1		1										
Network type 2		0.952										
Network type 3		1.226										
Network type 4		1.42										
Number of employees		2.02										
Accessibility measurement for female												
Network type 1			1									
Network type 2			0.951									
Network type 3			1.22									
Network type 4			1.412									
Number of employees			2.004									
Home accessibility measure												
Population density at home location												
<10 %tile								-4.325				
10th %tile							2.395					1.669
20th %tile										1.112		
30th %tile										0.951		
40th %tile (Base)												
50th %tile		0.628	0.553		-0.973							
60th %tile										0.844		1.481
70th %tile												
80th %tile			0.545		-0.723							
90th %tile			0.762									
Home accessibility (# of employees within 20min travel)												
<10 %tile		-0.748	-1.048									
10th %tile		-0.723	-0.953									
20th %tile			-0.711									
30th %tile												
40th %tile (Base)												
50th %tile		0.571				0.351						
60th %tile					-0.704							
70th %tile					-0.713			-3.426				
80th %tile		0.915	0.637									1.497
90th %tile		1.148	0.929					-3.782				

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	F1	F2	IND1	PUR1	PICK1	TRIP1	SHR	IND2	PUR2	PICK2	TRIP2
Household characteristics											
Number of vehicle											
0											
1(Base)											
2									0.665		
3									0.892		
Household income											
-10,000				-0.073							7.701
10,000-24,999							4.04				
25,000-34,999								-6.947			
35,000-49,999 (Base)											
50,000-74,999 (Base)											
75,000-99,999	0.329									-0.226	
100,000-149,999					0.206			4.875			0.886
150,000-							3.719				
Male head characteristics											
Age											
-25	1.21		16.853				-6.755	10.861			
26-35	0.899		15.152				-4.885	9.911			
36-45	0.966		12.437					7.958			
46-55	1.193		10.368								
56-65	1.119			0.726							
66-75	1.257			0.772							
75- (Base)											
Education											
5th-8th grade											
9th-12th grade											
High school graduate											
Some college											
Associate degree and other (Base)											
Undergraduate											
Some graduate school	1.026					3.004					
Master's degree											
Professional degree	0.989										
Doctorate or higher	0.743			0.572							
Ethnicity											
White/not hispanic	0.463										
Hispanic											
African American and other (Base)											
Asian											
Native american											
Other											
is student					0.505	2.044	3.941				
has license											
has disability											

continued in the next page

	F1	F2	IND1	PUR1	PICK1	TRIP1	SHR	IND2	PUR2	PICK2	TRIP2
Female head characteristics											
Age											
-25											
26-35											
36-45	0	0.714									
46-55	0	0.956				-0.234					
56-65	0	0.786									
66-75											
75- (Base)											
Education											
5th-8th grade											
9th-12th grade									-1.022		
High school graduate				-0.095				-4.704			
Some college				-0.102			3.263				
Associate degree and other (Base)											
Undergraduate							3.452				
Some graduate school										1.557	
Master's degree											
Professional degree				-0.215							
Doctorate or higher											
Ethnicity											
White/not hispanic											-1.216
Hispanic											
African American and other (Base)											
Asian									1.124		
Native american											
Other											
is student											
has license											
has disability											