An Intra-household Assessment of Land Use and Activity-Travel Behavior Patterns in California

Seo Youn Yoon
GeoTrans Laboratory, Department of Geography
University of California, Santa Barbara, CA 93106, USA
yoon@geog.ucsb.edu

and

Konstadinos G. Goulias
GeoTrans Laboratory, Department of Geography
University of California, Santa Barbara, CA 93106, USA
goulias@geog.ucsb.edu

ABSTRACT: At the core of land use and transportation interactions we find relations between spatial distribution of activity opportunities properly weighted by the impedance of reaching these opportunities and time allocation by individuals to activities and travel. Availability of opportunities changes with time and space (e.g., retail store spatial distribution in a city and opening and closing hours). Individuals' ability to reach them also varies with windows of possible engagement in activities within the daily schedule that are also influenced by the transportation systems status (e.g., free flow, congested, and so forth). Observed activity patterns are a function of the spatial distribution of activity opportunities, the level of service of the transportation system, and of the scheduling modalities followed by individuals (e.g., task allocation within households). To answer questions about land use policy potential to change travel behavior we need to first understand and describe the complex relationships among time allocation and travel of individuals within households, the role played by the spatio-temporal activity opportunity distributions surrounding them, and the transportation systems. In this paper, using data from the entire state of California, we present a statistically estimated and tested model system that shows the role land use and infrastructure play (i.e., using accessibility indicators) in behavioral decision making effecting a variety of behavior patterns in time use, resource allocation, and activity allocation of household members considered jointly in the same model system. Accessibility in this case study is defined as the ease with which a person reaches opportunities weighted by the amount of opportunities that can be reached. We employ different measures of accessibility to distinguish between location-centered (e.g., home-based, work-based, and school-based) as well as path-based accessibility to account for available time in daily schedules and reachable space. We also allow the accessibility of one person to influence the accessibility of another within the households studied. The models estimated are different among different segments of the population and they display clear gender-roles as well as specializations within households. This raises many issues of equity of policy impacts and motivates our recommendations for more detailed analysis at finer detail of geography and social segmentation.

Keywords: Time-space prismccessibility, land use, time allocation, intra-household interaction, structural equation model

Paper submitted to WCTR10, July 20010, Lisbon, Portugal

1. INTRODUCTION

Human interaction is one of the most important topics in understanding of human behavior and travel behavior is not an exception with substantial research devoted to 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). The result of the joint consideration of all these factors that influence decision making is 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 impacts bargaining between household members and allocating time to these activities. However, activity opportunity that is available to each household member has not 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 indicators and including them in travel behavior models. 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 (path-based) completely different from place-based approaches (location-based0. 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 the entire State of California. 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 times 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 variables, the equation is formulated as (2).

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

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(ζ)=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).

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

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 SEM. 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.

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

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

$$\text{Let } \mathrm{h} = (\mathrm{h}_1, \mathrm{h}_2, \dots, \mathrm{h}_\mathrm{n}). \tag{5}$$

Then

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

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

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

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 portion of 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 developed based on this structure.

To test activity priority orders 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 goodness of 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 uses 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

In this section, six 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.

They were compared to find a model that is conceptually desirable and not inferior in terms of model fit. The six model structures compared here are:

M1) *Model with discretized time-space prism accessibility measures*
The continuous accessibility measures are discretized into 4 categories each to test non-linear relationship between time-space prism accessibility and time use variables

M2) *Model with continuous time-space prism accessibility measures as they are*
The continuous accessibility measures are use as they are in this model. It has to be noted that the distribution of accessibility measures are highly skewed: measurement values are concentrated at zero because of the individuals who did not travel, and non-zero accessibility measures are also concentrated within a narrow bracket compared to the whole range of accessibility measures.

M3) *Model with logarithms of accessibility measures with base of e*
In order to modify the highly skewed distribution, natural logarithm was taken for the accessibility measures.

M4) *Model with endogenous accessibility factors*
Factors are introduced in addition to model M3 to represent latent accessibility and they were considered as endogenous variables. The effects of exogenous variables are linked to the factors.

M5) *Model with correlation specified between accessibility factors*
In addition to the model settings of M4, correlation is specified between the residual terms of the two factors to test the systematic correlation between them.

M6) *Model with home location characteristics*
In addition to the model settings of M5, home accessibility characteristics are added to the model as exogenous variables.

The model structures are compared with the two-person household sample of 4,830 households. The comparison of model fit is given in table 6.2. Between M3 and M4, another model was tested with accessibility factors as exogenous variables, but the model did not converge. This model was excluded from the comparison.

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). The sample size used for this test is large enough to make the p value of any model very small. Therefore, any of the six models was rejected because of their model fit. To confirm this, the same six model structures were tested on a randomly selected smaller sub-sample. The results verified that the models are 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. M1 shows the best model fit among the models that consider accessibility as an exogenous variable (M1 – M3). 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 becomes problematic for interpretation of the result because the discretized accessibility ignores the heterogeneity of accessibility experienced by different individuals.

Between M2 and M3, M2 shows better fit than M3, however when latent accessibility factor is introduced, only the accessibility variable setting used for M3 brings convergence to the model. Between M4 and M5 that consider accessibility as endogenous variable, M5 shows better fit implying that there exists correlation between the residual terms of accessibility factors. M6 expands M5 with home accessibility characteristics and shows non-inferior model fit than M5. M6, which corresponds with the conceptual model, well competes with the other possible model structures in terms of model fit. The comparison confirms that M6 is a suitable model for this study.

6.3 Interpretation of coefficients

The total effect from the result of the last model (M6) 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 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. 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. This implies that when one of the two heads schedules time for an independent activity the other person is more likely to allocate more time in independent activity too.
- 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, 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 in which women are employed.
- The negative impact of male's gaining accessibility on female's purchasing activity is the highest in the first group, but it does not 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 patterns. Male and female heads time allocation does not depend on each other's accessibility level and their time use is 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 genders except for 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 considering the spatial organization of activity locations and temporal constraints of each individual.

7. CONCLUSION

This paper proposes a time use model, including travel, that accounts for individual spatio-temporal constraints, as well as, land use and network infrastructure within an intra-household interaction framework. Variables representing land use and network infrastructure available for each individual are measured based on individual spatio-temporal constraints in persons' daily 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 behavioral 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 potentials to allocate time to certain types of activity. It also implies that people consider longer time span than one day, for which the survey data was collected, when they bargain on time use.

The findigs here suggest that consideration of interaction would reveal the impact of a policy on land use or network infrastructure with a 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.

ACKNOWLEDGEMENT

Funding for this project was provided by the National Highway Institute of the Federal Highway Administration through the Dwight David Eisenhower Graduate Transportation Fellowship, the University of California Transportation Center, the Department of Geography at the University of California Santa Barbara, the California Department of Transportation, and the Southern California Association of Governments, The contents of this paper do not constitute a policy at any level of government.

REFERENCES

Bhat, C.R., Pendyala, R.M. (2005) Modeling intra-household interactions and group decision-making. Transportation (2005) 32:443-448, Springer.

Bradley, M. and Vovsha, P. (2005) A model for joint choice of daily activity pattern types of household members. Transportation 32:545-571, Springer.

Burns, L. (1979) Transportation, temporal, and spatial components of accessibility. Lexington Books, Lexington, Mass.

Gliebe, J.P. and Koppleman, F.S. (2005) Modeling household activity-travel interactions as parallel constrained choices. Transportation 32:449-471. Springer.

Golledge, R. G. (1984). An anchor point theory of the acquisition of spatial knowledge and some empirical observations. Paper presented at the AAG meetings, Washington, DC.

Golob, T.F., McNally, M.G., (1997). A model of activity participation and travel interactions between household heads. Transportation Research B 31 (3), 177-194.

Hägerstrand, T. (1970). What about people in regional science? Papers and Proceedings of the Regional Science Association, Vol. 24, pp. 7-24.

Kim, H-M and Kwan, M-P (2003) Space-time accessibility measures: a geocomputational algorithm with focus on the feasible opportunity set and possible activity duration, LP Journal of Geographical Systems, 5:71-91.

Koenig, J.G. (1980) Indicators of urban accessibility: theory and application. Transportation, 9:145-172.

Kostyniuk, L.P. and Kitamura, R (1982) Life cycle and household time-space paths: empirical investigation, Transportation Research Record, 879: 28-37.

Kwan, M-P (1998) Space-time and integral measures of individual accessibility: a comparative analysis using a point-based framework, Geographical Analysis, 30:191-217

Miller, H.J. (1991) Modeling accessibility using space-time prism concepts within geographical information systems. International Journal of Geographical Information Systems 5: 287-301.

Miller H.J. (2005) Place-based versus people-based accessibility, in D. Levinson and K. J. Krizek (eds.) Access to Destinations, Elsevier, 63-89.

Srinivasan, K.K., and Athuru, S.R. (2005) Analysis of within-household effects and between-household differences in maintenance activity allocation. Transportation 32:495-521. Springer.

Srinivasan, S. and Bhat, C.R. (2005) Modeling household interactions in daily in-home and out-of-home maintenance activity participation. Transportation 32:523-544. Springer.

Tanaka, J.S. (1993) Multifaceted conceptions of fit in structural equation models. Testing structural equation models Ed. Bollen, K.A. and Long, J.S.

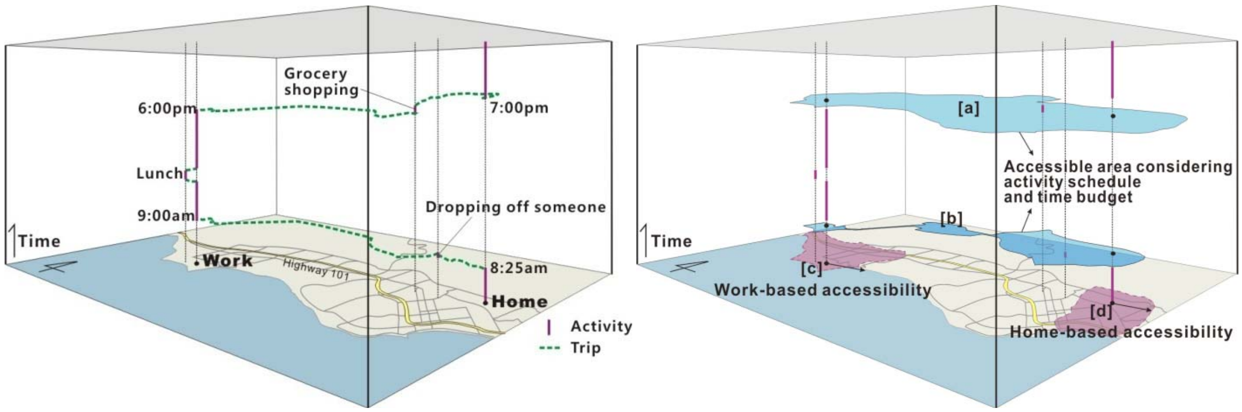
Weber, J. and Kwan, M-P (2002) Bringing time back in: a study on the influence of travel time variations and facility opening hours on individual accessibility, The professional geographer, 54(2):226-240.

Yoon, S.Y., Golob, T.F., and Goulias, K.G., (2009) A California statewide exploratory analysis correlating land use density, infrastructure supply and travel behavior, Proceedings of the 88th Annual Meeting of the Transportation Research Board, January 2009.

Zhang, J., Timmermans, H.J.P., and Borgers, A.W.J. (2002) A utility-maximizing model of household time use for independent, shared and allocated activities incorporating group decision mechanisms. Transportation Research Record, 1807: 1-8.

Figure1 Accessibility measurement based on individual space-time path.

A. **B**.



A. Space-time path of an individual for a day.

B. Accessibility measures

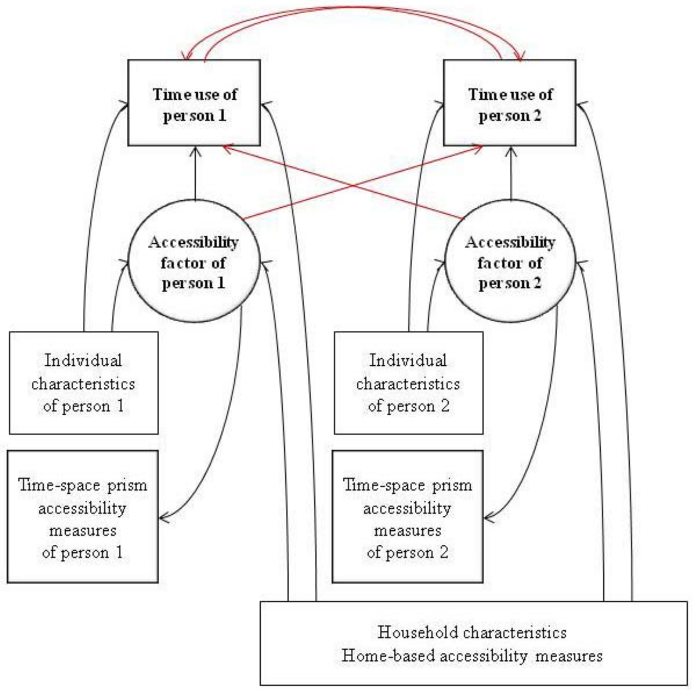
[a, b] Accessibility measured based on activity schedule and time budget.

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) 2-person interaction



B) 3-person interaction

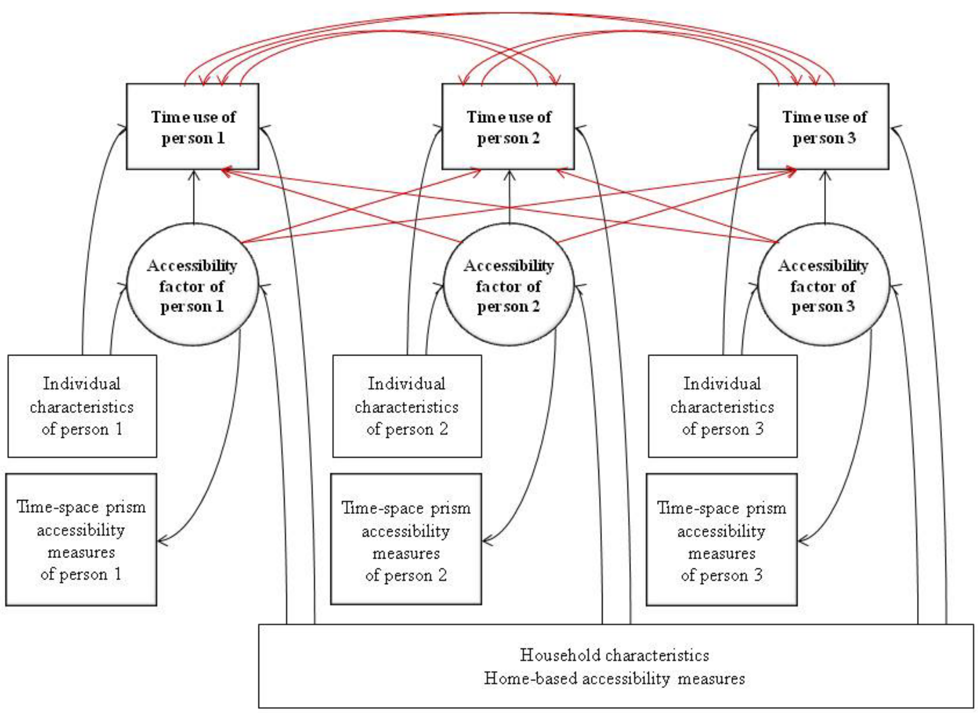


Table 1 Skeleton activities which constrains scheduling of the day (4830 couples without children)

	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	1) Independent Shared Allocated (PUR-PICK) Trips		2) Independent Shared Allocated (PICK-PUR) Trips		3) Shared Independent Allocated (PUR-PICK) Trips		4) 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	M1	M2	M3	M4	M5	M6
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 M6 model setting

		A(M)	A(F)	I(M)	PU(M)	PD(M)	T(M)	SHR	I(F)	PU(F)	PD(F)	T(F)
Endogenous variable												
Accessibility factor (Male)	A(M)			1.029	0.228	0.06	1.488	0.394		-0.14		
Accessibility factor (Female)	A(F)						-0.246	0.295	1.206	0.393	0.045	1.125
Male time use												
Independent	I(M)				-0.008		0.013	-0.174	0.7			
Purchasing	PU(M)						0.143			1.893		
Picking up/dropping off	PD(M)											
Trip	T(M)											
Shared activity	SHR				-0.013		0.04			-0.025		0.059
Female time use												
Independent	I(F)				0.016			-0.103		-0.024		0.022
Purchasing	PU(F)											
Picking up/dropping off	PD(F)											0.18
Trip	T(F)											
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				

continued in the next page

	A(M)	A(F)	I(M)	PU(M)	PD(M)	T(M)	SHR	I(F)	PU(F)	PD(F)	T(F)
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

	A(M)	A(F)	I(M)	PU(M)	PD(M)	T(M)	SHR	I(F)	PU(F)	PD(F)	T(F)
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											