Development of Time Varying Accessibility Measures: Application to the Activity-Based Model for Southern California Region

Rajesh Paleti  
Old Dominion University  
Civil & Environmental Engineering  
135 Kaufman Hall, Norfolk, VA 23529  
Phone: 512 751 5341  
Email: rpaleti@odu.edu

Peter Vovsha  
Parsons Brinckerhoff  
1 Penn Plaza, 3rd Floor, New York, NY 10119  
Phone: 212 465 5511  
Email: vovsha@pbworld.com

Rosella Picado  
Parsons Brinckerhoff  
999 3rd Ave #2200, Seattle, WA 98104  
Phone: 206 382 5227  
Email: Picado@pbworld.com

Bayarmaa Aleksandr  
Southern California Association of Governments  
818 W. Seventh Street, 12th Floor, Los Angeles, CA 90017  
Phone: 213 236 1834  
Email: Aleksandr@scag.ca.gov

Hsi-Hwa Hu  
Southern California Association of Governments  
818 W. Seventh Street, 12th Floor, Los Angeles, CA 90017  
Phone: 213 236 1834  
Email: hu@scag.ca.gov

Guoxiong Huang  
Southern California Association of Governments  
818 W. Seventh Street, 12th Floor, Los Angeles, CA 90017  
Phone: 213 236 1834  
Email: HUANG@scag.ca.gov

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Abstract
Traditionally, temporal variation of accessibility measures within a day is captured implicitly using time-of-day specific skims. However, another important dimension of accessibility measures that relates to the supply side is often ignored. This component is the temporal variation of supply side land use or zonal employment which constraints the availability of opportunities to undertake activities during certain hours. The current study develops a conceptual framework for developing time-of-day specific accessibility measures that account for these supply side effects and use these measures within an operational activity-based model (ABM) for the Southern California region. Overall, the descriptive analysis of the accessibility measures and the model estimation results of choice models in the ABM suggest that the measures are able to quantify the intended spatial and temporal accessibility effects quite well thus enhancing the land-use policy sensitivity of the overall model.
Introduction

Accessibility measures are important behavioral components of the activity-based models (ABMs) that express closeness of the modeled individual to potential locations where the activity “supply” (employment of the corresponding type) is present. While there is little doubt about the accessibility is a strong determinant of individual activity patterns, there is no consensus about how to measure and represent it functionally. So, there are wide array of accessibility measures developed in the literature each with its own merits and limitations (I). The most prominent among these measures include gravity based and opportunity based accessibility measures. While gravity-based measures indicate accessibility to attractions discounted by a impedance decay function, opportunity based measures represent cumulative accessibility to all attractions within a pre-selected boundary without any discounting based on travel impedance (2,3). Accessibility measures to support ABMs should be user-centric, i.e., these measures must be able to quantify what people perceive and affects their behavior. Similar dilemma is observed in highway operations. For instance, highway operation measures such as 90th percentile travel times are not user-centric measures of reliability. So, alternate measures such as entire trip buffer time (extra time that the traveler must plan as a buffer time) were developed because traffic operation measures could not be used directly. Similarly, in the context of accessibility measures, it is important to develop accessibility measures that are user and context specific, i.e., household auto-ownership specific, mode specific, and time-of-day (TOD) specific measures to be able to support advanced ABMs.

In most cases, temporal variation of accessibility is incorporated implicitly using TOD specific skims. However, there is also a dimension of spatial accessibility to activity opportunities which varies by TOD. It is difficult to construct accessibility measures which account for this time-varying nature of supply side land use effects because of data limitations (2). Recently, there have been attempts to developed space-time accessibility measures that account for temporal profile of opportunity centers as well as preferred activity participation durations of travelers. However, these methods rely on GIS-based techniques and are computationally intensive and time consuming. Also, most of these methods are auto-centric and extending these techniques to account for multi-modal scenarios is not a trivial task (4). In this study, we develop TOD-specific gravity type accessibility measures that account for both time-varying skims and land use supply effects. The context specific accessibility measures developed using the framework described in this paper were used in several behavioral choice models that feed into the ABM currently under development for the Southern California region. Each of these measures correspond to a given activity purpose and are sometimes further segmented by travel arrangement type, auto availability, and/or mode depending on what specific choice dimension is modeled. Special effort was made to make these accessibility measures properly differentiated by hour of day so that they can be linked to the corresponding time-of-day specific choices.

Methodology

As Figure 1 illustrates, accessibility measures are formalized such that they capture accessibility to all attractions and accessibility from all productions. The accessibility measures used in the Stage 2 ABM are essentially a sum of all attractions in the region discounted by the travel impedance. In its most elemental form, the accessibility for activity purpose segment \((p, q, r)\) in zone \(i\) during hour \(t\) is defined as:
where:
\( i, j \) = origin and destination zones, respectively,
\( t \) = hour of the day (starting 3 am),
\( p \) = activity purpose,
\( q \) = travel arrangement type (joint versus individual),
\( r \) = auto availability (zero cars, cars\(\leq\)number of adults, cars\(>\)number of adults),
\( M_{p,q,r} \) = set of modes applicable to activity purpose segment \((p,q,r)\) (can include one or more of the following 7 aggregate modes: SOV General Purpose Lane (GPL), SOV Toll, HOV GPL, HOV Toll, Walk to Transit (WT), Drive to Transit (DT), & Non-motorized (NM))
\( S_p^i[j] \) = attraction size variable for purpose \( p \) in zone \( j \) during hour \( t \),
\( C^i_{p,q,r,M_{p,q,r}}[i,j] \) = physical impedance measure (reflecting travel time, cost, distance etc) between origin \( i \) and destination \( j \) for purpose \( p \) of travel arrangement \( q \) of auto availability \( r \) using modes \( M_{p,q,r} \) during hour \( t \),
\( f() \) = decay function reflecting traveler perception of physical impedance and associated behavioral thresholds

**Underlying Nested Choice Structure Assumption**
The accessibility measures described by EQ(1) can be equivalently viewed as logsum derived from a nested choice model of trip destination choice, trip departure time-of-day (TOD) choice, and trip mode choice. The nesting structure underlying the accessibility measures in EQ(1) is described in Figure 2 below. The destination choice is at the upper level followed by trip departure TOD choice and mode choice at the second and third level nests, respectively. Although the figure shows only two time periods (peak and off-peak), one may use as many time periods as supported by the network skims. Destination choice that includes time-of-day choice and mode choice as lower-level choices represents the natural framework for accessibility since it reflects the composite utility of visiting a potential destination for the given activity.

**Size Variables**
It can be seen from EQ(1) that each of the accessibility measures is further segmented by hour of the day as indicated by the index \( t \). In the past, almost all attempts to incorporate time varying accessibility measures in travel demand models were driven by the travel impedance component of the accessibility measures. However, the other equally important component i.e. the size variable \( S_p^i[j] \) was assumed to remain constant across the entire day. Specifically, \( S_p^i[j] \) was replaced by \( S_p[j] \) which is the attraction size variable for the entire day. However, this simplification is behaviorally incorrect since opportunities to pursue different types of activities vary by TOD because any activity center has an active time window during which its services are available. For example, most retail shopping centers open around 9 am and close by 6 pm. In
fact, the opening and closing hours of these shopping centers have a time-of-day profile similar to the work start and end time profiles observed in the household travel survey data. So, the attraction size variable for shopping trips must gradually increase peaking around 9 am and then again start sloping downward from 6 pm in the evening. In such a scenario, it would be incorrect to assume that all retail centers are always open and thus attraction size variable remains constant all through the day.

The policy implications of ignoring this time varying nature of attraction size variables can be substantial given that past research and practical experience has shown that accessibility measures have significant impact on several long-term, medium-term, and short-term travel-related decisions of individuals. For instance, the observed TOD profile of number of people pursuing activities in a region is an outcome of equilibrium between the number of people who want to pursue activities on the demand side and the number of opportunities to undertake these activities on the supply side. So, any wrong assumptions about the TOD profile of opportunities on the supply side can have significant implications to the demand model forecasts.

One of the main innovations underlying the accessibility measures developed as part of Stage 2 model update is that these measures explicitly account for the time varying nature of attraction size variables based on empirical data observed in the real world. The next section of this document explains the methods and the data we used to accomplish this task.

The size variable measuring zone attraction for a given purpose \( p \) is specified as a linear combination of \( K \) different zonal land use (LU) variables, as follows:

\[
S_p'[j] = \sum_{k=1}^{K} \beta_{pk} \times LU_k'[j],
\]

(2)

where:

\( LU_k'[j] \) = \( k^{th} \) LU variable during time period \( t \),

\( \beta_{pk} \) = Impact of the \( k^{th} \) LU variable on zone attraction for purpose \( p \).

The time period specific value of these LU variables is obtained by multiplying the total zonal value by a time-of-day specific factor:

\[
LU_k'[j] = \delta_k'[j] \times LU_k[j],
\]

(3)

where:

\( LU_k[j] \) = \( k^{th} \) LU variable for zone \( j \)

\( \delta_k'[j] \) = time-of-day factor for \( LU_k[j] \) for hour \( t \) for zone \( j \)

The determination of values of \( \beta_{pk} \) in EQ(2) requires an additional step for estimation or calibration of a trip destination choice model. Alternatively, approximate estimates of these parameters can be obtained using a linear regression model (excluding constant) of total trip attractions on different land use variables. The land use variables used in EQ(2) are mostly zonal employment by different industry sectors. So, \( \delta_k' \) essentially represents the % of employment of the corresponding category during the time period \( t \). We used secondary data sources including Google Place data and InfoUSA data to create business hour profile for each employment sector which is subsequently used to estimate the \( \delta_k' \) parameters. We processed the Google place data for the Southern California region to obtain key information about business establishments.
including location coordinates, name of business, phone number, opening and closing times of the business. Based on the phone numbers in the Google Place data, we then appended information about the NAICS industry type using InfoUSA data. Preliminary estimates of the \( \delta_i^j \) factors for each TAZ were obtained using this secondary data source. Figure 3 shows the distribution of business hourly profile by industry sector for the entire SCAG region. It can be seen from the figure that across all industry sectors there is bell shaped profile with most businesses remaining open between 9 am and 6 pm. However, there are also some significant differences in the hourly profile among different industry sectors. Furthermore, it is not appropriate to use a single business hourly profile for the entire SCAG region since the temporal profile of businesses in a region can vary significantly depending on the characteristics of that region. For example, the temporal profile of businesses in the CBD region can be shifted to the right with more businesses open during late hours compared to non-CBD areas. Figure 4 shows the temporal profile of number of hours spent in shopping by people in the SCAG region segmented by CBD versus non-CBD areas. It can be seen from the figure that the temporal profile of shopping activities is shifted to the right in the CBD region. To account for this spatial variation of business hourly profile, we compute \( \tilde{\delta}_i^j \) specific to each TAZ.

In the secondary data sources, there were several businesses with incomplete information including missing location coordinates, missing phone numbers, and missing information about opening and closing hours. Also, it is not necessary that the business hourly profile and employment hourly profile are the same in any given region. For example, consider a TAZ with two businesses A and B where Business A has 100 employees and Business B has only 2 employees. The employment hourly profile in the TAZ is almost completely independent of the hourly business hourly profile of Business B. To account for this missing data problem and the inconsistency between businesses and employment, a spatial smoothing technique was used to improve the preliminary estimates \( \tilde{\delta}_i^j \) obtained directly using the secondary data sources. To be specific, the following spatial smoothing formula is used to obtain final estimate of \( \delta_i^j \) factors:

\[
\delta_i^j = \frac{\sum_j \tilde{\delta}_i^j \times \exp(-\gamma d_{ij}) LU_k^j}{\sum_j \exp(-\gamma d_{ij}) LU_k^j}
\]

where:
- \( \tilde{\delta}_i^j \) = time-of-day factor for \( LU_k^j \) for hour \( t \) for zone \( i \)
- \( LU_k^j \) = \( k \)th LU variable for zone \( j \)
- \( d_{ij} \) = Distance between TAZs \( i \) and \( j \)
- \( \gamma \) = Degree of spatial correlation in business pattern

If \( \gamma = 0 \), then it implies that the employment hourly profile is uniform across all TAZs. Alternatively, if \( \gamma = \infty \), then it implies that the employment hourly profiles of TAZs are completely independent of each other. In reality, the employment hourly profile of a TAZ is primarily averaged with that of adjacent TAZs which is captured by all intermediate values of \( \gamma \). For the SCAG model, a value of 0.5 was assumed for the \( \gamma \) parameter. It can be seen from EQ(4) that the influence of a neighboring TAZ \( j \) on \( \delta_i^j \) is weighted by the land use variable \( LU_k^j \) to
ensure that neighboring TAZs with larger employment have greater influence than neighboring TAZs with smaller employment. This weighting method also helps smooth the differences in the hourly profiles of businesses and employment.

Decay Function
Decay function represents traveler perception of physical space and associated measures like travel time, cost, distance, etc when they are transformed into probabilities of visiting different locations. Decay functions represent certain non-linear threshold effects that are pertinent to destination choices. For example, in some contexts for NM travel a 3-mile threshold is justified. In many other destination choice contexts, for example commuting, non-linear distance effects are frequently introduced to differentiate between different person types in addition to mode choice logsum where mode choice utilities are most frequently estimated in a linear form. The decay function adopted for this version of the SCAG ABM for measuring accessibility is the normalized mode choice logsum, defined as:

\[
f(C_{p,q,r,M,p,q,r}[i,j]) = \mu \times \ln \left( \sum_{m,M_{p,q,r}} \exp \left( \frac{V'_{m,p,q,r}[i,j]}{\mu} \right) \right),
\]

where:
- \( m \) = travel mode,
- \( V'_{m,p,q,r}[i,j] \) = observed portion of the mode choice model utility associated with mode \( m \) for a tour of purpose \( p \) made with travel arrangement \( r \) undertaken by an individual with auto availability \( q \)
- \( \mu \) = nesting parameter

The scaled mode-specific utilities are exponentiated and summed across the set of applicable modes. Natural log is then applied to the sum and re-scaled by the nesting parameter. The parameters that go into the utility function \( V'_{m,p,q,r}[i,j] \) must be obtained from the estimation or calibration of a simplified trip mode-choice model. However, for SCAG ABM, these parameters were asserted based on the normative values of the parameters known from the previously estimated mode and destination choice models for similar metropolitan areas in the nation. We plan to investigate additional non-linear decay functions applied in the destination choice models for accessibility calculations in future.

Aggregation over Time Periods
The hour-of-day specific accessibility measures can be further aggregated to obtain average accessibility measures for any time period as follows:

\[
A_{T_1,T_2}^{T_1,T_2}[i] = \ln \left[ 1 + \frac{1}{T_2 - T_1 + 1} \sum_{t=T_1}^{T_2} \exp \left( \tilde{A}_{p,q,r}^t[i] \right) \right],
\]

where \( T_1 \) and \( T_2 \) define the start and the end hours of the time period for which the accessibility measure is being computed and \( \tilde{A}_{p,q,r}^t[i] \) is obtained from EQ(1) without the “1” in the parenthesis as follows:

\[
\tilde{A}_{p,q,r}^t[i] = \ln \left( \sum_{j=1}^f S_p^t[j] \exp \left( f(C_{p,q,r,M,p,q,r}[i,j]) \right) \right)
\]
This aggregation formula is equivalent to using the average value of the size variable \( S'_p[i] \) between \( T_1 \) and \( T_2 \) in EQ(1).

Following from EQ(6), the daily average accessibility for segment \((p,q,r)\) is given by:

\[
A_{p,q,r}[i] = A_{p,q,r}^{1,24}[i] = \ln \left[ 1 + \left( \frac{1}{24} \right) \sum_{t=1}^{24} \exp \left( \tilde{A}'_{p,q,r}[i] \right) \right].
\] (8)

This is a very useful method to test accessibility measures in different choice models of the SCAG ABM. For instance, for modeling time allocation decisions within a tour, the analyst can use aggregated accessibility measures between the tour start time \( T_1 \) and end time \( T_2 \): \( A_{p,q,r}^{T_1,T_2}[i] \). Similarly, while modeling long-term usual work location choice, the analyst can use daily accessibility measure \( A_{p,q,r}[i] \).

**Aggregation over Time Periods with TOD-specific Constants**

Additional TOD-specific constants need to be incorporated in the decay function (EQ 5) when calculating the aggregate accessibility measures for certain models simulated prior to TOD decisions being made. This set of accessibility measures are labeled with the prefix “AVG_” to distinguish them from their counterparts that do not incorporate the TOD-specific constants. The addition of these constants does not require re-calculating the elemental accessibility measures. Indeed, these constants can be factored out of the decay function \( f() \) and the aggregate form of accessibility measures can be simplified as follows:

\[
AVG_\pi A_{p,q,r}^{T_1,T_2}[i] = \ln \left[ 1 + \left( \frac{1}{T_2 - T_1 + 1} \right) \sum_{t=T_1}^{T_2} \exp \left( \text{in}_P [t] \lambda_{PMPK,p} + \text{in}_O [t] \lambda_{OP,p} + \tilde{A}'_{p,q,r}[i] \right) \right] \] (9)

where \( \text{in}_P[t] \) and \( \text{in}_O[t] \) are indicator variables for whether hour \( t \) corresponds to PM Peak period and Off-peak periods, respectively; \( \lambda_{PMPK,p} \) and \( \lambda_{OP,p} \) are time-period specific constants that indicate mean preference for the corresponding time periods in the TOD choice model.

Following from EQ(9), the daily average accessibility that incorporates TOD-constants is given by:

\[
AVG_\pi A_{p,q,r}[i] = AVG_\pi A_{p,q,r}^{1,24}[i]
\]

\[
= \ln \left[ 1 + \left( \frac{1}{24} \right) \sum_{t=1}^{24} \exp \left( \text{in}_P [t] \lambda_{PMPK,p} + \text{in}_O [t] \lambda_{OP,p} + \tilde{A}'_{p,q,r}[i] \right) \right]
\]

\[
= \ln \left[ 1 + \left( \frac{1}{24} \right) \left( \sum_{t=1-13,7-12,17-24} \exp \left( \lambda_{OP,p} + \tilde{A}'_{p,q,r}[i] \right) \right) + \sum_{t=1-16} \exp \left( \tilde{A}'_{p,q,r}[i] \right) \right] \] (10)

**Descriptive Analysis**

Figure 5 depicts accessibility to all individual non-mandatory activities between 11 am and Noon for auto, transit, and non-motorized modes. Bottom left corners of transit and non-motorized accessibility plots show the corresponding mode infrastructure in the SCAG region. It can be
seen from the figure that these different measures do not duplicate each other but portray different aspects of accessibility. For instance, transit accessibility is concentrated along specific corridors where transit facilities are available where as auto accessibility is radially symmetric around the city center. Non-motorized accessibility, on the other hand, is spatially discrete with some spatial pockets with very low accessibility surrounded by regions with high accessibility which suggests that this measure captures localized accessibility. Also, non-motorized accessibility plot is consistent with the pedestrian and bicycle infrastructure in the region. Figure 6 is an illustration of the temporal profile of accessibility to individual shopping activities across all modes for different car sufficiency levels. Two important observations may be made from this figure. First, at any given hour, the relative order of accessibility is no cars, low auto sufficiency (number of cars< number of adults), and high auto sufficiency (number of cars>number of adults). Second, the temporal profile of accessibility measures across all car sufficiency levels follows a bell-shaped curve which is consistent with the temporal profile of size variable (i.e., opening and closing business hours) observed in Figure 2.

Summary of Impacts of Accessibility on Activity and Travel Choices
Several different types of zonal accessibility measures were incorporated in the SCAG ABM. The necessity to use a variety of accessibility measures stems from the need to use different combinations of size variables and impedance measures for different choice models in the ABM depending on the household auto sufficiency level, modes, activity/travel purpose, and time periods. Figure 7 is an illustration of the combination of different types of size variables and impedance measures underlying the accessibility measures used in different model components of the SCAG ABM. It can be seen from the figure that there are two components to accessibility measures: size variable and impedance measure. The first component, size variable, can be either a daily measure or TOD-specific. Similarly, the second component, impedance measure can be across all modes, mode-specific, daily, or TOD-specific. Unlike in most other ABMs, it is not necessary to pre-calculate a fixed set of accessibility measures a priori. Depending on the choice context, different combinations of these two components may be used to obtain the most appropriate accessibility measure for any given choice model in the ABM.

For example, the daily household time allocation model that determines daily activity participation decisions of all members in the household uses accessibility measures obtained using daily size variables and daily impedance measures across all modes because the decisions being modeled are daily planning decisions where modes and departure times associated with each of the activities are not yet known (5). On the other hand, it is more appropriate to use daily size variables and daily mode-specific accessibility measures in the auto ownership model since it is the relative values of accessibility by different modes that drives the auto ownership decisions in a household. Similarly, TOD-specific choices such time allocation within a tour to different activities is an example of choice context within SCAG ABM where the tour start time and end time is already known but the tour mode is yet to be determined. For this model, we use TOD-specific size variables and TOD-specific impedance measures across all modes and use EQ(6) to obtain the appropriate accessibility measure to be used during model estimation. Moreover, as Figure 5 illustrates there are three versions of each accessibility measure corresponding to a different auto sufficiency levels. So, we use auto sufficiency specific accessibility measures because we know the household composition and auto ownership levels for all short term choice models (in fact, all models downstream the auto ownership model in
SCAG ABM). In the next two paragraphs, we briefly summarize the impact of different types of accessibility measures on choice models in the SCAG ABM.

Long term choice models in SCAG ABM include car ownership and license (mobility attributes), work arrangement, and work location. Households residing in zones with high auto accessibility and low transit and non-motorized accessibility are more likely to own multiple cars. Also, high auto accessibility and low transit accessibilities were found to increase the probability of holding a valid driver’s license. The work arrangement model predicts the weekly work hours for primary job, number of jobs, and primary workplace type place for all the workers in a household. Employed people residing in zones with high daily accessibility across all modes to work tend to have multiple jobs and are less likely to work from home. This may be because people residing in these zones have better opportunities to find multiple jobs and their commute is also relatively easier compared to people with low work accessibility. The usual work location choice model predicts the primary work location of employed people in the SCAG region. Results suggest that zones with high daily accessibility to all non-mandatory activities across all models are not preferred work locations compared to zones with low accessibility to non-mandatory activities. This parameter is probably capturing the urbanization diseconomies due to high land prices, and low environmental quality of life in the neighboring area (for example, noise and air pollution).

One of the first models in the activity-generation step of activity-travel simulator is out-of-home daily non-mandatory activity participation model that predicts all the activity participation and time allocation decisions in non-mandatory activities (individual and joint) by activity purpose and participation group of individuals. Since this is a daily-level planning model, we tested three types of accessibility measures: between 6 am and 9 am, between 9 am and 6 pm, and between 6 pm and 11 pm. Our intent was to see if higher accessibility during specific time periods is more likely in increase activity-participation rates of certain types of activities. However, in the final model, only accessibility measures between 9 am and 6 pm came out to be statistically significant. Specifically, higher accessibility to non-mandatory activities across all modes and between 9 am and 6 pm was associated with higher likelihood of participating in shopping, maintenance, and active recreational activities. Also, higher accessibility to joint non-mandatory activities between 6 am and 9 pm was associated with higher probability of participation in joint entertainment activities.

At the scheduling step, one of the important tour-level models is the tour frequency model that predicts the number of non-mandatory individual tours which a person undertakes. Two accessibility measures are used to inform this model: the non-mandatory accessibility using all modes (conditional on vehicle ownership) and the non-mandatory accessibility using non-motorized mode. Since the time-of-day in which the tours start and/or end is not known at this stage of the model, the hour-specific accessibilities are averaged over the time window in which the tour can occur. These time windows are defined as follows: 1) Accessibility for before work tour = average hourly accessibility values from 6:00 AM to work departure time, if work departure time occurs after 6:00 AM, or the accessibility for the hour in which work departure occurs, if earlier than 6:00 AM. 2) Accessibility for after work tour = average hourly accessibility values from arrival at home (from work) until 11:00 PM, if home arrival occurs before 11:00 PM, or the accessibility for the hour in which the person arrives at home from work, if later than 11:00 PM. 3) Accessibility for work based tour = average hourly accessibility values from work arrival time to work-to-home departure time. 4) Accessibility for non-worker tours = average hourly accessibility values from 6:00 AM to 11:00 PM. The work-based tour
frequency model uses accessibilities measured from the work TAZ, while all other models use accessibilities measured from the home TAZ. Overall, the coefficient on accessibility variables is positive implying that higher accessibility increases the likelihood of making a tour.

The subsequent model in the scheduling step is the primary purpose of tour model that predicts the primary purpose of all the non-mandatory individual tours predicted by the tour frequency models. Two accessibility measures are used to inform this model: the non-mandatory accessibility using all modes (conditional on vehicle ownership) and the non-mandatory accessibility using non-motorized mode. Since the time-of-day in which the tours start and/or end is not known at this stage of the model, the hour-specific accessibilities are averaged over the time window in which the tour can occur. For workers, accessibility (all modes) to maintenance activities increases the probability of having maintenance as the primary purpose of after-work tours, whereas, accessibility (all modes) to shopping increases the probability of having shopping as the primary purpose of before-work tours. For non-workers, higher accessibility to entertainment and eat-out purposes increases the likelihood of having those activities as the primary purpose of the tour.

The next model in the scheduling step is the non-mandatory tour window model that predicts the tour window (i.e., tour departure time from home and tour arrival time at home) of each of the non-mandatory tours. The models take the form of a multinomial logit model with alternatives defined as combinations of 15 minute windows of start and end times (6). Accessibility variables for each combination of start and end time alternative is calculated using EQ(6). Three accessibility variables are considered: (i) the non-motorized accessibility to all non-mandatory activities, (ii) all-modes accessibility to all non-mandatory activities, and (iii) the all mode accessibility to activities of the primary purpose of the tour. The accessibility of the primary purpose for during the tour window of the tour is significant and positive in all the models except the tour window models for work-based tours indicating that people tend to schedule their tour when the accessibility to their primary purpose of tour is the most. A higher accessibility for the primary purpose of the tour decreases the likelihood of tours with longer tour durations. Higher home based accessibility to purpose-specific activities was associated with higher likelihood of making a stop of that purpose within the tour for all home-based non-mandatory tours. Higher work based accessibility to purpose-specific activities was associated with higher chance of participating in activities of that purpose within work-to-home commute tours.

The next important model in scheduling step is time allocation within the tour model which predicts the time allocated to different activities in individual non-mandatory tours. By this stage in the SCAG ABM, we already know the tour purpose and the departure time from home and tour arrival time at home, i.e., tour window. The tour time allocation model allocates time within the tour window to different non-mandatory individual activities. Overall, higher home based accessibility across all modes between the tour window to purpose-specific activities was associated with higher likelihood of making a stop of that purpose within the tour for all home-based non-mandatory tours. Similarly, higher work based accessibility across modes between the tour window to purpose-specific activities was associated with higher chance of participating in activities of that purpose within work-to-home commute tours. The subsequent model in the scheduling step is a model that predicts the stop frequency, activity purpose, and the order (or sequence) of stops in both outbound and inbound direction of each individual non-mandatory tour. To capture the land-use and level-of-service effects, we have used the average accessibilities to different activity purpose from home (for outbound direction) and from primary
destination (for inbound direction) over the tour time window. The results suggest that an activity tends to have more number of stops if the accessibility to that activity is higher from home/primary destination.

Overall, depending on the choice context, several accessibility measures were found to have a significant impact on long term choices, short term activity generation choices, and short term scheduling choices enhancing the land-use policy sensitivity of the SCAG ABM.

**Conclusion**

The accessibility measures developed in this paper are capable of enhancing the policy sensitivity and behavioral realism of the SCAG ABM. In particular, they are better than the measures used in several other ABMs developed elsewhere in one or more of the following ways:

1. Consider accessibility by multiple modes (auto, transit, & non-motorized) instead of just auto mode
2. Consider several impedance measures (cost, travel time, wait time, transfer time, number of transfers, access time) instead of a simple travel time or cost based impedance measure
3. Consider impact of different levels of car sufficiency on accessibility
4. Use different types of size measures instead of broad categories such as retail or service employment
5. Explicitly account for time varying employment within a day in a TAZ
6. Can be easily aggregated between different time windows to capture the impact of accessibility on planning as well as scheduling decisions
7. Can fully support different choice dimensions of various sub-models of the SCAG ABM.

While the current study is an important step forward in terms of accounting for time-varying nature of supply side land use variables on demand models, it is not necessarily true that we imply causality. People might be going late night to do shopping in Manhattan because there are shops open late night. On the other hand, it is also true that shops are open late night because business owners see people coming late night. So, in reality, what we observe is demand-supply equilibrium. So, to make these ABMs operational and behaviorally realistic, we need to iterate between land use models that predict spatial and temporal distribution of key land use characteristics in the region and ABMs that predict the activity-travel patterns of people residing in the region. This situation is very similar to the use of travel times and travel costs in mode choice models of ABMs. While it is true that network conditions impact travel patterns, it is also true that travel patterns in turn determine the network conditions. So, to make use of these time-varying accessibility measures, we need integrated land-use and activity-based models just as how we need integrated activity-based and dynamic traffic assignment models to accurately capture the impact of network conditions on travel patterns (7).
References
Figure 1 General Form of Accessibility Measures

Accessibility to Attractions

Home or Work

Shop 1

Shop 2

Shop 3

Figure 2: Nesting Structure underlying Accessibility Measures

Choice of Destination \( j \) for Origin \( i \)

Dest 1

Dest 2

Dest 3

…

Dest N

Choice of time period \( t \) for Destination \( j \)

Peak Time Period

Off-Peak Time

Choice of Mode (\( m \)) for Time Period (\( t \)) & Destination (\( j \))

SOV

SOV Toll

HOV

HOV Toll

Walk Transit

Drive Transit

Non-Motorized
Figure 3: Hourly Business Profile in the Southern California Region

Figure 4: Hourly Profile of Hours Spent in Shopping in the Southern California Region
Figure 5: Accessibility to Non-Work Attractions in the SCAG Region
Figure 6: Temporal Profile of Accessibility to Shopping Activities for Different Auto Sufficiency Levels

Figure 7: Mapping of Size Variables, Impedance Measures & Accessibility Measures