An Innovative Methodological Framework to Analyze the Impact of Built Environment Characteristics on Activity-Travel Choices

Chandra R. Bhat
The University of Texas at Austin
Department of Civil, Architectural & Environmental Engineering
1 University Station C1761
Austin TX 78712-0278
Phone: 512-471-4535, Fax: 512-475-8744
E-mail: bhat@mail.utexas.edu

and

Jessica Y. Guo
University of Wisconsin-Madison
Department of Civil and Environmental Engineering
1206 Engineering Hall
1415 Engineering Dr
Madison, WI 53706-1691
Phone: 608-890-1064, Fax: 608-262-5199
Email: jyguo@wisc.edu

1. INTRODUCTION

There has been an increasing interest in the land use-transportation connection in the past decade, motivated by the possibility that design policies associated with the built environment can be used to control, manage, and shape individual traveler behavior and aggregate travel demand. In this line of research and application pursuit, it is critical to understand whether the empirically observed association between the built environment and travel behavior-related variables is a true reflection of underlying causality or simply a spurious correlation attributable to the intervening relationship between the built environment and the characteristics of people who choose to live in particular built environments.

To be sure, there is an expanding and lively body of literature debating the causal versus the associative nature of the relationship between the built environment and travel behavior (we will use the term built environment or BE in this paper to refer to land-use, urban form, and street network attributes). Another dimension of the debate is whether any causal effect of the built environment on travel behavior is of adequate magnitude to actually cause a discernible shift in travel patterns. These issues are at the heart of the potential effectiveness of design policies manifested in "new urbanism" and "smart growth" concepts. While there are the polarized groups of ardent proponents and opponents of the new urbanism/smart growth concepts, the body of scholarly and applied works regarding the potential effect of BE attributes on travel patterns is at best mixed and inconclusive. A review by Ewing and Cervero (2001) describes several studies that found reasonably significant elasticity effects of the BE attributes on travel demand variables. Some more recent studies have also found significant effects of the BE on one or more dimensions of activity/travel behavior (see Rajamani *et al.*, 2003; Krizek, 2003; Shay and Khattak, 2005; Bhat *et al.*, 2005; Bhat and Singh, 2000; and Rodriguez *et al.*, 2005). However, several studies reviewed by Crane (2000) and some other works (see, for example, Boarnet and Sarmiento, 1998; Boarnet and Crane, 2001; Bhat and Lockwood, 2004; Bhat *et al.*, 2005; and Bhat and Zhao, 2002) have found that BE measures have little to no impact on such dimensions of travel behavior as activity/trip frequency and non-motorized mode use. In addition, because of the widely varying estimation techniques, units of analysis, empirical contexts, travel behavior dimensions, and BE characteristics and their scales used across the studies, it is difficult to compare and contrast results. The net result is that there is reasonable agreement in the academic field that, despite the explosion of empirical studies in the past 15 years, it is still premature to draw any conclusive evidence regarding the impacts of the BE on activity-travel behavior. Further, two major inter-related problems need to be carefully addressed and recognized as we move forward in improving our understanding of the relationship between the BE and travel behavior: (1) The relationship between the BE and travel behavior can be very complex, and (2) The "true" causal impact of the BE on travel behavior can be assessed only if the spurious association due to residential sorting based on demographics and other characteristics is controlled for. Each of these two issues is discussed in turn in the next two sections (see also Boarnet and Crane, 2001; Crane, 2000; Krizek, 2003; and Handy, 1996).

2. COMPLEX NATURE OF THE BUILT ENVIRONMENT-TRAVEL BEHAVIOR RELATIONSHIP

There are at least three elements characterizing the complex relationship between the BE and travel, as briefly discussed below.

2.1 Multidimensional Nature

The first element of the complex relationship between the BE and travel is that both of these are multidimensional in nature. That is, there are many aspects to the BE, including accessibility to transit stops, presence and connectivity of walk and bike paths, land-use mix, street network density (such as average length of links and number of intersections per unit area), block sizes, and proportion of street frontage with buildings. Similarly, there are many dimensions of travel, including car ownership, number of trips, time-of-day, route choice, travel mode choice, purpose of trips, and chaining of trips. A fundamental question then is what dimension of the BE impacts what dimension of travel, a seemingly innocuous, but very complex, question to address. Many earlier research works have focused on the impact of selected BE characteristics on selected travel dimensions. Such analyses provide only a limited picture of the many interactions leading up to travel impacts. In particular, the use of a narrow set of BE measures potentially renders the measures as proxies for a suite of other BE measures, making it difficult to identify which element of the multidimensional package of BE measures is actually responsible for the travel impact. Similar to the use of a narrow set of BE attributes, the focus on the impacts of the BE on narrow dimensions of travel does not provide the overall effect on travel. For instance, a denser environment may be associated with less of pick up/drop off activity episodes, but more of recreational episodes (see Bhat and Srinivasan, 2005). The net impact on overall travel will depend on the "aggregation" across the effects on individual travel dimensions. Finally, most empirical analyses consider a trip-based approach to analysis, ignoring the chaining of activities and the resulting intricate interplay of the effect of BE attributes on the many dimensions characterizing activity participation and travel.

2.2 Moderating Influence of Decision-Maker Characteristics

The second element of the complex relationship between BE measures and travel is the moderating influence of the characteristics of decision makers on travel behavior (individuals and households). These characteristics may include sociodemographic factors (such as gender, income, and household structure), travel-related and environmental attitudes (such as preference for non-motorized/motorized modes of transportation and concerns about mobile source emissions), and perceptions regarding the BE attributes (that is, cognitive filtering of the objective built environment attributes). The decision maker characteristics may have two kinds of moderating influences: (1) a direct influence on travel behavior (for example, higher income households are more likely to own cars), and (2) an indirect influence on travel behavior by modifying the sensitivity to BE characteristics (for example, it may be that high income households, wherever they live, own several cars and use them more than low income households; this creates a situation where high income households are less sensitive to BE attributes in their car ownership and use patterns than low income households). Almost all individual and household-level analyses of the effect of BE characteristics on travel behavior recognize and control for the direct influence of decision-maker attributes by incorporating sociodemographic characteristics as determinants of travel behavior. A handful of studies also control for the direct impact of attitudes and perceptions of decision-makers on travel behavior (see Schwanen and Mokhtarian, 2005; Kitamura *et al.*, 1997; Handy *et al.*, 2005; and Lund, 2003). However, while there has been recognition that the sensitivity to BE attributes can vary across decision-makers (see Badoe and Miller, 2000), most previous empirical studies have not examined the indirect effect of demographics on the sensitivity to BE attributes. And, to our knowledge, no earlier study has recognized the potential effect of unobserved decision-maker characteristics on the response to BE attributes. On the other hand, it is possible that the varying levels and sometimes non-intuitive effects of BE attributes on travel behavior found in earlier empirical studies (for example, in Bhat and Gossen, 2004 and TRB, 2003) is, at least in part, a manifestation of varying BE attribute effects across decision-makers in the population.

2.3 Spatial Scale of Analysis

The third element characterizing the complex relationship between the built environment and travel is the "neighborhood" shape and scale used to measure the BE measures. Most studies use predefined spatial units based on census tracts, zip codes, or transport analysis zones as operational surrogates for neighborhoods because urban form data is more readily available and easily matched to travel data at these scales. However, it is anything but clear as to how individuals perceive the "neighborhood" space and scale, and how they filter spatial information when making spatial choice decisions (see Golledge and Gärling, 2003; Krizek, 2003; and Guo and Bhat, 2004, 2006 for detailed discussions of this issue). Further, it is possible that different BE attributes have different spatial extents of influence on travel choices, as empirically illustrated by Guo and Bhat (2006) and Boarnet and Sarmiento (1998).

3. RESIDENTIAL SORTING BASED ON TRAVEL BEHAVIOR PREFERENCES

The second major issue in the BE-travel behavior relationship is residential sorting based on travel behavior preferences. A fundamental assumption in almost all earlier research efforts is that there is a one-way causal flow from the BE characteristics to travel behavior. Specifically, the assumption is that households and individuals locate themselves in neighborhoods and then, based on neighborhood attributes, determine their travel behaviors. Thus, on the basis of these studies, if good land-use mixing has a negative influence on the number of motorized trips, the implication would be that building neighborhoods with good land-use mix would result in decreased motorized trips in the population, with a concomitant decrease in traffic congestion levels. A problem with the above line of reasoning is that it does not take a comprehensive view of how individuals and households make residential choice and travel decisions. In reality, households and individuals who are auto-disinclined, because of their demographics, attitudes, or other characteristics, may search for locations with high residential densities, good land-use mix, and high public transit service levels, so they can pursue their activities using non-motorized travel modes. If this were true, urban land-use policies aimed at, for example, increasing density or land-use mix, would not stimulate lower levels of auto use in the overall population, but would simply alter the spatial residence patterns of the population based on motorized mode use desires. Ignoring this self-selection in residence choices can lead to a "spurious" causal effect of neighborhood attributes on travel, and potentially lead to misinformed BE design policies.

The literature that has considered the self-selection issue (also refereed to as the residential sorting issue) in assessing the impact of BE attributes on travel choices has done so in one of three ways.

3.1 Controlling for Decision-Maker Attributes

The first approach is to control for demographic and other travel-related attitudes/perceptions of decision-makers that may impact the neighborhood type individuals choose. This can be accomplished by incorporating decision-making characteristics as explanatory variables in models of travel behavior. This is a creative, and simple, way of tackling the self-selection problem, but its use in practice is limited by the fact that most travel survey data sets do not collect attitudinal data. Further, it is unlikely that all the demographic and travel lifestyle attitudes that have any substantive impact on residential sorting can be collected in a survey, because of which it becomes difficult to gauge how close the estimated BE effects are to the "true" causal effect.

3.2 Instrumental Variables Approach

The second approach to alleviate the residential sample selection effect is to use a two-stage instrumental variable approach where the endogenous "explanatory" BE attributes are first regressed on instruments that are related to the BE attributes, but have little correlation with the randomness in the primary travel behavior of interest. The predicted values of the BE attributes from this first regression are next introduced as independent variables (along with other demographic attributes of the individual) in the travel behavior relationship of interest. A problem with the instrumental variable approach as discussed above, however, is that it is not applicable to the case where the travel behavior equation of interest has a non-linear structure, such as a discrete choice or a limited/truncated variable. There are control function and related approaches today to deal with the case of endogenous "explanatory" variables in the context of discrete choice and other non-linear models (see Berry *et al.*, 1995; Lewbel, 2004; Louviere *et al.*, 2005), but these methods need rather tedious computations to recognize the sampling variation in the predicted value of the endogenous BE attributes to obtain the correct standard errors in the main equation of interest. The alternative of ignoring the sampling variance in the predicted values of the BE attributes, as done by Boarnet and Sarmiento, can lead to incorrect conclusions about the statistical significance of the effects of the BE attributes.

3.3 Using Before-After Household Move Data

The third approach to alleviate the residential sorting effect is to examine the travel patterns of households immediately before and immediately after a household relocation. The potential advantage of examining the same household in two different neighborhoods is that one can ostensibly control for the overall travel desires and attitudes of the members of a household, so that the before-after relocation changes in travel behavior may be attributed to the different built environments in the two neighborhoods. The essential idea in this approach is to consider the relocation as a "treatment", with the associated travel behavior changes being the response variable. The assumption one would make in such an analysis is that relocating households are in equilibrium in their pre-move neighborhood in terms of BE attributes, and moved because of factors unrelated to their preference of BE attributes (such as to upgrade the physical housing stock in response to higher incomes or a change in lifecycle). While such a longitudinal approach is one way of alleviating the self-selection problem, a problem with the approach is that the relocating households are themselves a self-selected group, and may have moved because of dissonance in the pre-move neighborhood BE attributes vis-à-vis their desired configuration of BE attributes.

4. PROPOSED MODELING FRAMEWORK

In the current research effort, we contribute to the literature on BE-travel behavior interactions by addressing some of the challenges discussed in the previous two sections. In particular, we propose a modeling framework that (a) accommodates differential sensitivity to the built environment and transportation network variables due to both demographic and unobserved household attributes and (b) controls for the self-selection of individuals into neighborhoods based on travel preferences. The framework can be used to control for residential self-selection for any kind of travel behavior variable and directly provides the correct standard errors regarding the effect of the built environment attributes. It is geared toward cross-sectional analysis, recognizing that almost all existing data sources available for analysis of BE effects are cross-sectional in nature. Unlike earlier studies, the methodology also explicitly considers and models the residential location choice decision jointly with the travel behavior choice of interest.

The results of applying the model formulation to an empirical analysis of residential choice and car ownership decisions of San Francisco Bay area residents will be presented at the innovative modeling conference, if the paper is accepted. The important findings from this application are as follows. First, BE attributes do affect residential choice decisions as well as car ownership decisions. Thus, policy decisions regarding changes in BE characteristics have to be evaluated in the joint context of both decisions, so that spatial relocation patterns as well as car ownership changes can be analyzed. Such a complete picture enables a comprehensive assessment of potential travel-related changes due to BE policies. Second, our findings support the notion that the commonly used population and/or employment density measures are actually proxy variables for such BE measures as street block density and transit accessibility. Third, in the context of car ownership decisions, both household demographics and BE characteristics are influential. However, household demographics have a more dominant effect. Fourth, there is variation in sensitivity to BE attributes due to both demographic and unobserved factors, in both residential choice as well as car ownership decisions. But, while the study examined a suite of demographic interactions and allowed random variations in sensitivity to several BE characteristics, most of these did not turn out to be statistically significant. Among demographics, income is a key variable in affecting the sensitivity to BE attributes and related variables. Unobserved household-specific factors also play an important role in the sensitivity to commute time and street block density (in the residential choice model) and employment density and street block density (in the car ownership model). Ignoring such systematic and random variations in sensitivity to BE attributes will, in general, lead to inconsistent results regarding the effect of BE attributes on travel behavior decisions, which can, in turn, lead to inappropriate policy decisions. Fifth, household income is the dominant factor in residential sorting. Specifically, low income households consciously choose to (or are constrained to) locate in neighborhoods with low commute costs, long commute times, and high employment density compared to their high income counterparts. Such low income households also intrinsically choose to own fewer cars. Thus, ignoring income effects in car ownership (and by extension, other travel decisions) can lead to an inflated effect of the built environment and related variables on travel behavior decisions. Other demographic factors that impact residential sorting based on car ownership preferences correspond to the presence of senior adults in the household and whether or not a person lives alone. Finally, and rather surprisingly, our results did not support the notion of residential sorting in car ownership propensity based on unobserved household factors. This result implies that independent models of residential choice and car ownership choice (after accommodating the residential sorting effects of demographics) are adequate to examine BE effects on car ownership choice, in the current empirical context. But, in general, it is important to consider the methodology developed in this paper to control for the potential presence of self selection due to both observed and unobserved household factors. Only by estimating the joint model can one conclude about the potential presence or absence of self-selection effects due to unobserved factors.

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