The Influence of Built-Form and Land Use on Mode Choice

Evidence from the 1996 Bay Area Travel Survey

Michael Reilly and John Landis

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Abstract

Although land use planning and urban design are increasingly touted as powerful tools for influencing transportation behavior, only modest empirical evidence for this relationship exists. Here, the results from a two-day activity diary are combined with innovative GIS-based measures of urban form and land use pattern to statistically test potential influences on non-commute home-based mode choice. Local measurement at multiple scales is promoted as a realistic means of quantifying an individual's perception of the neighboring urban environment, and multinomial logit models are specified for various trip purposes. In all models tested, the inclusion of measures of urban form or land use pattern improves the model. Generally, the measurable role of physical factors is small; however, their influence is relatively large in a model predicting station access mode choice.

INTRODUCTION

Interest in how the built environment influences transportation behavior has increased significantly in recent years. Concerned that traffic congestion and urban sprawl are overwhelming the human scale of American metropolitan areas, an increasing number of planners, architects, urban policy analysts and even politicians are promoting the reorganization and redesign of cities as a means of reducing the problems associated with an auto-dominated transportation system. Plans and neighborhood development forms that emphasize pedestrian comfort and convenience, these advocates argue, will promote increased walking and transit use, thereby reducing auto use and freeway congestion. And because such forms will necessarily be more compact, they will also help to reign in sprawl.

The most vocal advocates of this position are the New Urbanists and other promoters of neo-traditional design. Starting in the late 1980s, the New Urbanist movement argued for a return to traditional town-planning with its emphasis on more fine-grained, pedestrian-scale development patterns (Kelbaugh 1989; Calthorpe 1993; Katz 1994; Duany 2000). To date, nearly two dozen New Urbanist communities have been completed or are under development. Among the most notable are the Kentlands outside of Washington, DC; Laguna West, south of Sacramento, California; and Celebration, near Walt Disney World in Florida. New Urbanist design principles have been embraced by the US Department of Housing and Urban Development in its HOPE VI program, and by the National Governor's Conference in its recent publication, "New Community Design to the Rescue: Fulfilling Another American Dream" (2001).

Underlying the New Urbanist movement is a belief that designing neighborhoods, communities, and regions to be more compact and walkable will result in increased pedestrian activity, increased transit use, and decreased reliance on the private auto. Backing up this belief is the observation that people in suburbs and lower-density neighborhoods generally drive more while people in center cities and higher-density neighborhoods are more likely to take transit or walk. A closer look at the issue, however, raises deeper questions regarding cause and effect. Walking is typically easier, transit is more ubiquitous, and parking is generally dearer in older, denser cities—raising the possibility that residents of such places self-select precisely to take advantage of the greater diversity of transportation services. If indeed communities can be designed not just to be more transit- and pedestrian-friendly, but to actually get people out of their cars, then the effect of urban form on travel behavior—most notably mode choice—must be found to be consistent and robust for the fullest possible array of travelers and trip types.

This research is an empirical investigation of the effects of land use form on home-based non-work travel behavior among residents of the San Francisco Bay Area. Conceptually, it draws on prior theoretical and empirical research into the effects of neighborhood-scale urban form on mode choice decisions. (See, for example, Cervero 1996, Kockelman 1998, and Crane and Boarnet 2001.) Practically, it makes use of the results of a detailed survey of trip-making behavior conducted by the Metropolitan Transportation Commission in 1996. Its principal contribution is two-fold. First, and foremost, it focuses on non-work trips—already the majority of daily household trips—as opposed to more frequently studied work trips. Second, it makes use of the analytical power of geographic information systems (GIS) to more precisely measure aspects of urban form at the scale of the trip-maker rather than at the zonal scale.

The remainder of this paper briefly reviews recent research into the influences of built-form on transportation behavior, then presents a series of discrete choice models of non-work mode choice incorporating trip-maker demographic characteristics, selected trip characteristics and transit supply measures, and multiple measures of built-form. These models are tested and their results are interpreted. Finally, the research is summarized and future research directions are suggested.

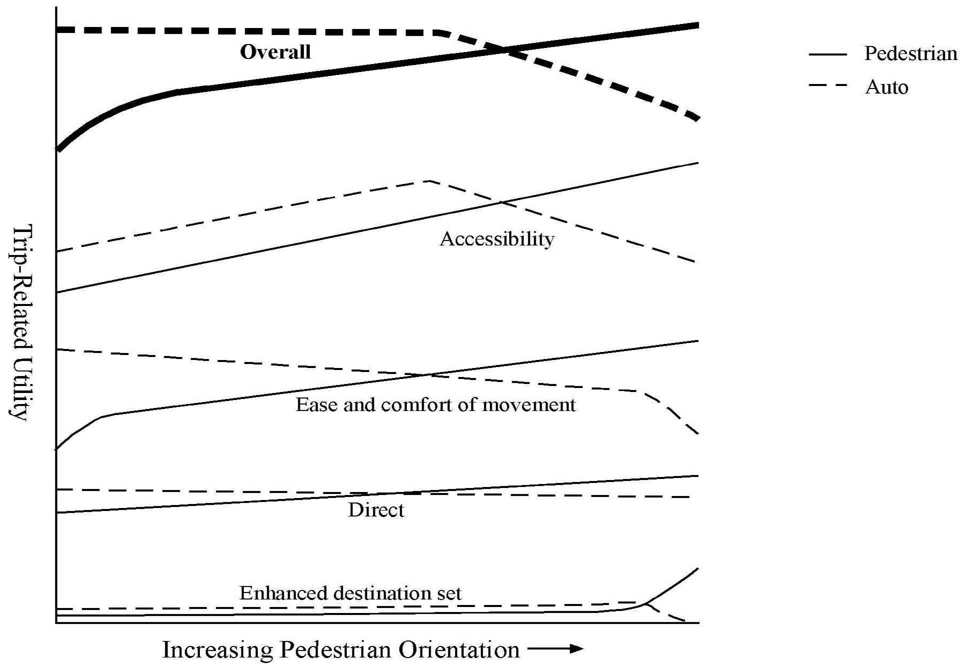
SHOULD BUILT-FORM MATTER? THEORY AND EVIDENCE

Utility Theory as a Conceptual Approach to Travel Behavior

Travel is typically regarded as a derived demand. Rather than valuing travel for its own sake, trip-makers are presumed to choose their travel routes and modes on the basis of the cost and convenience of getting from a pre-selected origin to one or more pre-selected destinations. Following McFadden (1974), such choices are typically modeled empirically within a random utility framework.

Built-form affects travel utility in four ways. At a very basic level, physical improvements such as sidewalks and easy-to-cross streets increase the relative comfort and ease of movement associated with travel in urban environments. Pedestrians and drivers may value these improvements differently. Pedestrians and, to a lesser extent, bicyclists will tend to see them as improving comfort and convenience. Drivers on the other hand—if they notice them at all—may view the same set of improvements as reducing their travel speeds and increasing their travel costs. The inverse relationship between ease of walking and ease of driving is shown schematically in Figure 1.[1]

Figure 1: Theoretical Relationship between Urban Form and Trip-Related Utility



Second, and probably more important, are the effects of density. As densities increase—that is, as buildings get taller—the number of similar activities within easy walking distance also increases. The same is true for mixed-use development which, if properly done, improves accessibility to a variety of complementary activities. Greater variety, we assume, translates into increased utility, particularly in the case of non-work trips.

The advantages of density are less obvious for car and work trips. Parking spaces are more expensive and difficult to find in higher density urban environments. This is particularly true for discretionary trips, where reserved parking is seldom available. More to the point, higher residential and commercial densities are usually associated with street congestion, adding to overall travel times. Whereas the utility of walking trips rises with increasing density, the utility of auto travel tends to decline, particularly for short trips. The relationship between density and transit is more complex still: vehicles like subways, bus rapid transit and monorails, which have their own right-of-ways, permit travelers to enjoy the increased opportunities associated with higher densities while avoiding problems of congestion and parking. Buses and light-rail vehicles, on the other hand, are generally affected by street congestion in the same way as private cars.

Higher densities are associated not only with more of the same or similar activities, they are also associated with a greater variety of activities. This is particularly true for retailing. When enough potential customers live, work or travel within a small geographic area, retail demand rises to the point where it may be sufficient to justify the increased inventory and freight costs associated with stocking a greater variety of goods. This is precisely why department stores developed first in central cities. In turn, the synergy of complementary retailers adds to the utility associated with a particular retail destination, thereby further increasing the demand for travel.

Third, high-density urban environments also afford opportunities for increased personal encounters, as well as paradoxically, opportunities for greater anonymity. These relationships are presented as *enhanced destination set* utility in Figure 1.

Last, there may be direct benefits associated with particular trip types and travel modes, especially in cities. Strolling along New York's Fifth Avenue, Chicago's Michigan Avenue, or Paris's Champs-Élysées is its own enjoyment, whether or not one has a particular destination in mind. The joys of travel are certainly not limited to walking—what would suburban life in America be like without Friday night cruising? Still, with the spreading of traffic congestion from city to suburb and from weekday to weekend, recreational driving is now increasingly done off-road. Some people even enjoy riding buses and subways just for the fun of it.

In sum, there is a convincing argument to be made that the built environment influences the utility of travel, both directly and indirectly. Such utility gains, however, are likely to be different for different groups of travelers, for different trip purposes, and for different modes.

Review of Empirical Research

It is one thing to conceptualize relationships between built-form and travel behavior. It is quite another to identify whether those relationships are important in the real world. Researchers have employed a variety of approaches to try to capture such relationships empirically. Empirical studies relating built-form and travel behavior can be organized along three dimensions: (i) the types and purposes of travel behavior considered; (ii) the scale at which built-form is measured and analyzed, and whether analysis is aggregate or disaggregate; and, (iii) the types of built-form characteristics considered.

Types of Travel Behavior. Aggregate analyses consider how travel patterns vary as a function of area-wide or zonal averages. Traffic analysis zones are typically larger than neighborhoods, making it difficult to gather detailed measurements of urban form. More to the point, aggregate analyses typically suffer from problems of ecological fallacy, in which phenomena occurring at different spatial scales are clumped together in ways which lead to biased comparisons. Disaggregate analyses aim to avoid these problems by considering behavior at the level of the individual. Hybrid studies combine aspects of aggregate and disaggregate analyses.[2]

Aggregate Analysis. Transportation planners have undertaken zonal-based analyses of travel behavior since the 1950s. Such analyses were broadened in the 1970s to consider measurements of density, including residential densities at trip origins and commercial densities at trip destinations (Pushkarev and Zuppan 1977). Driven by concerns over energy consumption and global warming, researchers in the 1980s began investigating aggregate relationships between urban form and mode use by comparing various cities worldwide. Newman and Kenworthy (1989) led this effort with a global comparison of the relationships between metropolitan densities, mode shares, and vehicle-miles-traveled (VMT). Observing that auto mode shares decreased as densities increased, they called for densification as a means of promoting resource conservation and reducing air pollution. Although their initial work was widely criticized as too aggregate, a recent update (1999) goes beyond simple density measurements to also consider urban form.

The 1990s saw a number of studies that compared transportation patterns in different neighborhoods across one or a number of metropolitan areas within the United States. Holtzclaw (1990) analyzed odometer readings to compare the average annual vehicle-miles-traveled (VMT) by a household across five San Francisco Bay Area neighborhoods. Independent variables included population density and local serving job density. He found approximately five times as many VMT in the least dense neighborhood compared to the most dense. In 1994, Holtzclaw extended this analysis in a study to support Location Efficient Mortgages. He compared 27 zip-code-sized neighborhoods in the Los Angeles, San Francisco, San Diego, and Sacramento metropolitan areas and added more measurement of urban form and transit supply. He found that higher densities resulted in less auto ownership and lower VMT.

In the LUTRAQ (Land Use, Transportation, and Air Quality) Study for Portland Metro, Parsons Brinkerhoff Quade and Douglas, Inc. (1993) developed the pedestrian environment factor (PEF) in an attempt to capture built-form characteristics that make walking more pleasant. The index considered ease of crossing the street, continuity of sidewalks, grid versus cul-de-sac street networks, and hilliness. Neighborhoods with a high PEF were found to have lower VMT and more use of non-auto modes, at least if they were surrounded by other neighborhoods with a high PEF.

While some results from aggregate studies seem to indicate that built-form characteristics may influence travel behavior, the failure for these studies to control for socio-demographic factors that tend to be highly correlated with the built environment (e.g., poorer people tend to live at higher densities) means that any patterns uncovered may be spurious. Matched-pair studies aim to remedy this by picking pairs of neighborhoods that differ in their built-form characteristics but are more-or-less the same in terms of socio-demographics and regional accessibility.

Friedman, Gordon, and Peers (1992) compared a few “standard suburban” and “traditional” neighborhoods in the San Francisco Bay Area and found the latter—with its gridded street system and mixture of land uses—to have fewer auto trips than the former. Cervero and Gorham (1995) compared Bay Area and Los Angeles area neighborhoods in pairs where both were near each other and had similar socio-demographic characteristics but where one was a “transit” neighborhood and the other an “auto” neighborhood. They measured a variety of urban form characteristics and found that some transit neighborhoods had more transit use for the work trip. However, because this relationship only held for the Bay Area neighborhoods, they conclude that scale is an important consideration with local neighborhood characteristics only encouraging transit use when the region is also conducive to transit.

Aggregate studies of how transportation decisions vary across different neighborhoods and cities provide some indication that built-form characteristics, such as population density and overall pedestrian environmental quality, might influence these decisions. In short, they vary the overall bundle of form characteristics that make up a neighborhood while assuming that the socio-demographics of the neighborhoods do not impact travel significantly or by comparing neighborhoods where the socio-demographics are known to be largely the same. While matched-pair studies begin to disentangle the unique effects of built-form, disaggregate analysis is useful in understanding the behavior of individuals in a particular setting and for estimating the component impacts of particular micro built-form characteristics on travel choices.

Disaggregate Analysis. Because travel choices are made by individuals or households, disaggregate analyses of these decisions are more soundly grounded in social science theory. The use of multivariate statistical approaches to model transport outcomes at the individual, household, or trip level allows for the simultaneous consideration of the sociodemographic, environmental, and trip-specific characteristics that influence these choices and model variations at the level where it actually occurs. The embedding of these models in the choice theory offered by microeconomics connects them to an existing and rigorous theoretical framework, while approaching the problem at an individual level aids efforts in understanding the behavioral processes that underlie these decisions.

Hanson (1982) was perhaps the first researcher to employ a disaggregate approach in hopes of understanding the influence of the built environment on travel choices. He counted the number of stores and measured the variety of land uses in one-kilometer increments moving outward from each study residence in Uppsala, Sweden.[3] While socio-demographic factors proved more important than urban form characteristics, he found that higher densities led to higher trip frequencies and that residents with many shopping opportunities in the vicinity had shorter trips, though this was not true for recreational and social travel.

Handy (1992) compared non-work trip-making in four parts of the San Francisco Bay Area with a focus on the scale of accessibility and particular travel purposes. She selected the locations to fit into a two-by-two matrix considering local and regional accessibility and considered how socio-demographics and a variety of home-based accessibility and urban form measures influenced mode choice for trips to the grocery store, the regional mall, and other local and regional non-work destinations. She found more variation between neighborhoods than within them and found a number of accessibility variables significant at individual levels, but the models offered little overall explanatory power.

Handy (1996b) examined travel diary data from two Bay Area cities and tested the effect of blocks per square mile, cul-de-sacs per road mile, commercial establishments per person, and access to retail centers on non-work trips. She found a higher non-work trip frequency in areas with greater access, and built-form effects were greater than socio-demographic effects when comparing trip frequencies between traditional and suburban neighborhoods. Handy, Clifton, and Fisher (1998) examined recreational walking and shopping trips in Austin. They modeled the number of walking trips as a function of socio-demographics and a wide range of environmental variables. A perception of safety, seeing others on the street, and shade were found significant.

The LUTRAQ study mentioned above (Parsons Brinkerhoff Quade and Douglas, Inc. 1993) also contained disaggregate models predicting trip frequency and VMT. Although the urban form factors (discussed above) had little explanatory power, the socio-demographic factors explained little more. Ewing, Haliyur, and Page (1994) considered travel diaries from Palm Beach County, Florida, in relation to residential and employment density, jobs–housing ratios, percentage of multifamily housing units in the vicinity, and an accessibility index. They examined mode, trip frequencies, and travel time and found that people living in places with high accessibility tended to have shorter trip chains and spent less time traveling overall.

Kitamura et al. (1994) performed a detailed examination of five neighborhoods in the San Francisco Bay Area. Information on travel, socio-demographics, attitudes, and perception of the physical environment was collected from households, and physical characteristics of the neighborhoods were compiled. Total number of trips and proportions of trips by mode were modeled and both socio-demographics and attitudes proved more important than built-form characteristics. Kitamura, Mokhtarian, and Laidet (1997) performed additional analyses with the same dataset and found that difficulty in parking decreases the total number of trips and the proportion of trips by car. High residential densities led to more bike and walking trips, and greater distance to rail stations and having a backyard led to less transit use. In all, they found that attitudinal factors remained more important than urban form.

Cervero (1996) examined American Housing Survey data for eleven metropolitan areas in an effort to understand how land use mix affects commute mode choice. He found people more likely to use transit if they had commercial land uses in the vicinity, lived in medium or high density areas, lived a short distance from work, and had few cars available. Cervero and Kockelman (1997) used travel diary data for 50 San Francisco Bay Area neighborhoods and found that urban form affected mode choice and VMT but that socio-demographics had a larger influence.

Disaggregate multivariate studies allow for the simultaneous modeling of the varied factors thought to influence travel at the level of analysis where decisions are made. “Choice models” take this approach a step farther by explicitly couching individual-level decision models in a theoretical framework relating to the manner in which an individual goes about making such decisions. By far, the most common choice model employed by transport researchers is the supply and demand framework provided by microeconomics. Microeconomic discrete choice models view travel decisions, such as mode choice and trip frequency, as efforts by an individual to maximize his or her utility by making tradeoffs between the resources available to an individual—such as money, vehicles, and time—and the costs associated with a particular type of trip. Until recently, transportation choice models have seldom included urban form factors except in understanding the commute trip. However, the last decade has increasingly applied microeconomic theory to the modeling of non-work trips with an emphasis on possible influences of the built environment.

The first studies grounded in economics that explicitly considered the role of urban form in travel decisions were by Kain and Fauth (1976, 1977) and looked at the influence of land use patterns, density, transport supply, and workplace location on car ownership and mode choice. They looked at individual-level data from over 100 metropolitan areas and constructed transportation demand models. Overall, some built-form characteristics, such as proximity to rail transit and residential density, affect mode choice but mostly by way of auto ownership.

Crane (1996b) developed a model of trip demand that aims to link urban form to travel demand by means of “an explicit characterization of trip costs.” To build a simple model, he considered only travel time, meaning that the price of a trip represents the amount of time it takes. Different urban form factors have different impacts on trip time and length, thus impacting the overall cost of travel or the differential costs of travel by a particular mode. Crane’s model allows for the generation of a number of comparative static results, specifically that efforts to increase access lead to less costly trips which, in turn, lead to more trips but also to shorter trips. Overall, the combined impact of these changes in producing more or less travel is unclear and must be answered empirically.

Crane and Crepeau (1998) tested this model using travel diary data from San Diego County. They regressed the total number of non-work trips and the mode choices for these trips on “prices, income, taste variables, and other controls including land use variables.” Because they had no way of costing the multitude of built factors they predicted would influence travel choice, they employed each household’s median trip time (included as trip speed and trip distance) as a proxy. They tested the influence of the street patterns, street density, commercial proportion of the census tract, and distance from downtown. The trip cost variables were significant—households with longer or slower average trips tended to make fewer trips. Households with a large share of commercial land near by tended to make more trips.

Boarnet and Sarmiento (1998) used the same basic demand model, but approached the problem of measuring trip costs differently by assuming that built-form measurements fully capture trip costs, making the inclusion of trip time unnecessary. Using travel diary data from Orange County, they jointly modeled non-work travel decisions and the choice of residential neighborhood. While treating residential location as endogenous, they found employment and retail density to have significant impacts on trip demand when they were measured at the zip code level (but not at the smaller tract level).

Boarnet and Crane (1998, 1999, 2001) used both datasets and both approaches from the two previous papers above. The models that ignored residential location fit Crane's theory in that only when land use variables have an impact on trip prices do they have an impact on trip generation. People that live in tracts with more commercial land use were found to have shorter trip distances and slower speeds. However, the two-stage model (with residential neighborhood land use endogenous) again showed some evidence that the street pattern and amount of commercial use in the vicinity might be associated with fewer non-work car trips. Most relationships remain ambiguous with Crane (1999) concluding "beyond trips being sensitive to trip costs, this work has identified few, if any, transparent influences of the built environment on travel behavior that hold generally" (p 27).

Kockelman's dissertation (1998) firmly grounded non-work travel decision-making in modern demand theory and tested the influence of a wide variety of urban form measurements on travel. She modeled travel times and costs as choice variables and used urban form measurements such as access to jobs, land use mix, and density to determine these travel times and costs. Overall, urban form measures do not enter the trip demand models directly.

Overall, previous empirical work has been inconclusive regarding specific relationships between built-form and travel behavior, but has made progress in situating this type of empirical question within a theory of human behavior. A variety of studies have found that people living in higher density areas or places with greater access to commercial activities are more likely to use a non-auto mode. A few researchers have noted relationships between urban design characteristics and behavior, but there is little consistency. The ad hoc and often incomparable nature of these findings has led some researchers to spend more time incorporating built-form characteristics into a microeconomic decision-making framework. This study considers a wide range of urban environments, focuses on trips that are most likely to be impacted by built-form, and measures a wide variety of urban structure and form characteristics in a more rigorous manner than previous work.

RESEARCH APPROACH

This research explores the effects of urban form on individual mode choice decisions made by travelers in the San Francisco Bay Area in 1996. It combines detailed household travel behavior data with GIS-based measurements of urban form to construct a series of multinomial logistic regression models of mode choice for a variety of non-work trip purposes. While conceptually similar to prior research—especially that of Crane and Boarnet (2001) and Cervero and Kockelman (1996)—it is more precise in its consideration of trip types and purposes as well as in its measurements of urban form. It is also more varied in the types of neighborhood forms considered.[4] The general form of the models tested is as follows:

$$\mathbf{Prob}\ [\mathbf{m_i} \mid \mathbf{M}] = \mathbf{f}\ [\ \mathbf{SE_i}, \mathbf{T_i}, \mathbf{UF_{ij}}]$$

where:

m denotes the non-work travel mode chosen by traveler **i**
from the set of possible travel modes, **M**

$\mathbf{SE_i}$ indicates the socioeconomic characteristics of traveler **i**

$\mathbf{T_i}$ indicates selected characteristics of the trip taken by traveler **i**

$\mathbf{UF_{ij}}$ indicates the urban form characteristics of the home location of traveler **i**, measured at multiple scales, **j**

Following logic first suggested by McFadden (1974), individuals are assumed to make travel decisions to obtain the greatest amount of satisfaction (i.e., utility) possible within the constraints imposed by their income, household role, time, location, and transportation supply. An individual's preferences determine how the various characteristics of potential choices are evaluated in order to arrive at the utility-maximizing choice. Because the interaction between these various constraints and heterogeneous tastes is extremely complex and because information on the relevant price signals involved is generally lacking, this type of decision is most often modeled in a reduced form discrete choice framework. Each of the model variables is explained in greater detail below.

The BATS96 Sample

Detailed travel behavior and household characteristic data were obtained from the Metropolitan Transportation Commission's 1996 Bay Area Travel Survey (BATS96), a two-day travel diary containing travel and socio-demographic data for 14,431 individuals belonging to 5,861 households. Although broadly representative of all Bay Area households, the BATS96 sample frame was constructed to slightly over-sample geographic areas with extensive transit service.

Of the 10,269 home-based non-work trips made by BATS96 respondents over the age of sixteen, 7,915 were by car, 461 were by bus or rail transit, and 1,893 involved walking or bicycling (see Figure 2).

Figure 2 Mode Split of Home-Based Non-Work Trips By Persons Over 16

Mode	Number of Trips	Percent of Trips
Drive	7,915	77.1%
Transit	461	4.5%
Walk/Bicycle	1,893	18.4%
All Modes	10,269	100.0%

Prior to releasing the BATS96 dataset, MTC geocoded the street addresses of BATS96 respondents to latitude and longitude coordinates. This allows comparison of the locations of BATS96 respondents with other geographic datasets, including: (1) the Association of Bay Area Government's 1995 hectare-scale land use database; (2) the Census Bureau's 1995 and 2000 TIGER street files; and, (3) assessor's parcel data, as obtained from Metroscan. Altogether, a total of 3,089 home locations were successfully address-matched.

Socio-demographic Characteristics and Travel Behavior

Trip-maker socio-demographic factors such as age, gender, and ethnicity are included in travel behavior models for two reasons: first, because they may directly influence travel behavior; and second, as proxies for more difficult-to-observe factors such as preferences, tastes, resource constraints, and social conventions. Income and vehicle access, for example, are good indicators of an individual's access to resources, whereas gender, age, and ethnicity variables provide partial hints as to an individuals' tastes and travel preferences. Specific socio-demographic factors were entered into the models as follows:

Income and Auto Availability. Household income or, when normalized to family size, household income per member is thought to have a strong impact on mode choice. Upper-income households and persons are thought to place a higher value on the comfort and convenience associated with the private auto, particularly for non-work and discretionary trips.[5] The empirical record is not so clear, however, particularly in the case of work trips. Recent research by Kockelman (1996) using MTC's own BATS96 dataset demonstrates that wealthier individuals are sometimes more likely to take transit or walk. The variables *HH_INCOME* and *HH_INC/HH_SIZE* measure the household income and household income per member of each BATS96 respondent.

Auto availability usually tracks household income. All else being equal, as the number of automobiles available to a household increases—either in absolute terms or normalized to the number of persons per household—the probability that an individual trip-maker will drive is also expected to increase. Once purchased, an automobile is a "sunk cost," meaning that the cost of any individual trip is small compared to the initial capital outlay required to buy the vehicle. This situation makes the auto mode relatively more attractive for each of these particular trips and suggests the importance of modeling auto ownership as endogenous to mode choice (as in Kockelman 1998). Average auto availability per household (*HH_AUTOAVAIL*) among non-work trip-makers in the BATS96 sample was 1.8 vehicles; average auto availability per person (*PER_AUTOAVAIL*) was .63 vehicles.

Previous empirical work demonstrates that having a driver's license greatly increases the probability that an individual will drive, regardless of trip purpose or auto availability. The dummy variable, *DV_DRVLIC*, indicates whether or not each BATS96 survey respondent held a driver's license. For the sample as a whole, 74% held driver's licenses.

Age. The relationship between age and travel behavior is multi-faceted. Young children, for example, are far less likely than adults to make any type of independent trips. Teenagers, on the other hand, are wont to travel for just about any reason, but mostly just to get out of the house. Adults tend to travel out of necessity or for purposes of recreation. Older people often have the time and desire to travel, but may have physical difficulties taking extensive walking or bicycling trips. Attitudes toward specific modes also vary generationally, with older generations more familiar with, if not predisposed toward, transit. With respect to the BATS96 non-work trip-maker sample, the median age was 37.4 years. About a quarter of the sample were under 18 years old, and just over ten percent was over 65. Three measures of age are included in the models: the square of the trip-maker's age (*AGE_SQUARED*) and separate 0/1 dummy variables indicating whether the trip maker was less than 18 years old (*DV_YOUNG*) or more than 65 years old (*DV_OLD*).

Gender. Relationships between gender and travel behavior are also multi-faceted. What may be true for some men or women may be decidedly untrue for others. Many women, for example, are less willing than men to make trips or take modes they perceive as unsafe. Most household-related trips, including driving children to different activities are still undertaken by moms, not dads. Teenage boys are more likely to own a car or drive than teenage girls. And although things are changing, women have traditionally had reduced rates of car availability and been more transit-dependent than men. With respect to the BATS96 non-work trip-maker sample, women constituted just over half of the sample. Two gender measures are included in the models: *DV_FEMALE*, a dummy variable indicating whether or not the trip-maker was a woman; and *DV_MOM*, a dummy variable indicating whether the trip-maker was a mother to children under the age of 16.

Race, Ethnicity, and Immigration Status. Theory offers little guidance regarding the effects of race, ethnicity, and immigration status—net of age, gender and income—on travel behavior. Some have speculated that recent immigrants from countries with non-auto-dominated transport systems might continue to use alternatives in the US. Among the BATS96 non-work trip-maker sample, African-Americans, Asian and Pacific Islanders, and Hispanics accounted for 6%, 9%, and 12% respectively, of the sample. No information was available on immigration status. As is typical, dummy variables are used to model the effects of race and ethnicity on mode choice.

Employment Status. Employed people may have greater demands on their time, and thus prefer quicker and more convenient modes such as the private car to slower or less convenient modes. Seventy percent of BATS96 respondents were employed in 1996; the dummy variable, variable *DV_EMPLOYED*, measures whether or not an individual respondent was employed.

College students, while busy, tend to follow regular study schedules and may not need the speed or flexibility of a private car. Student parking is also scarce, further discouraging car use. Twenty percent of the BATS96 sampled individuals were full-time students in 1996; the dummy variable, *DV_STUDENT* indicates whether or not an individual respondent was a student.

Household Composition and Housing Type. If a household is a *Family*, interrelationships between individuals may have large impacts on each individual's choices. If household members are unrelated, they may share information or tastes, but their behavior is generally expected to be less interdependent. The greater the number of children (*KidNum*) in a family, the more likely adult family members are to avoid transit because they will have to pay a fare (though often a reduced one) for each person.

Finally, a household's dwelling unit type and housing tenure have traditionally been seen as a taste variable that may indirectly impact mode choice. Living in a single-family dwelling (*SFD*) or owning one's dwelling (*Own*) are expected to increase the likelihood that a person drives.

Other Factors. An individual's disability status is also expected to impact their choice of mode. If a disability seriously impacts a person's ability drive, see, or walk, they may have little choice but to use transit or depend on other drivers to get where they want to go. One percent of the BATS96 sample of non-work trip-makers reported having a disability that significantly limited their mobility. The dummy variable, *DV_DISABLED*, is used to indicate those trip-makers with mobility-impairing disabilities.

The amount of education a person has received may influence their tastes for various modes, but it is unclear in what manner. The variable *EDUCATION* measures the number of years of education for each BATS96 respondent.

Figure 3 summarizes key socio-demographic information for the BATS96 sample of non-work trip-makers.

Figure 3: Select Person- and Household-Level Socio-demographic Variables

Trip-maker Characteristic	Mean	Standard Deviation	Observations
Age	37.4	21.1	7,873
Share over 65	0.11	0.31	7,873
Share under 18	0.26	0.44	7,873
Female share	051	0.50	7,975
African-American share	0.06	0.24	7,803
Hispanic share	0.12	0.32	7,803
Asian-American share	0.09	0.29	7,803
Share disabled	0.01	0.08	7,819
Share w/Driver's License	0.74	0.44	7,969
Share Employed	0.70	0.46	6,434
Full-Time Student share	0.20	0.36	7,990
Share in Family	0.92	0.27	2,352
Income	9.53	3.69	3,113
Automobiles owned	1.8	0.99	3,618
Auto ownership share	0.63	0.48	3,599
Share residing in detached home	0.63	0.48	3,618

Built-Form and Mode Choice: Relationships and Measurement Issues

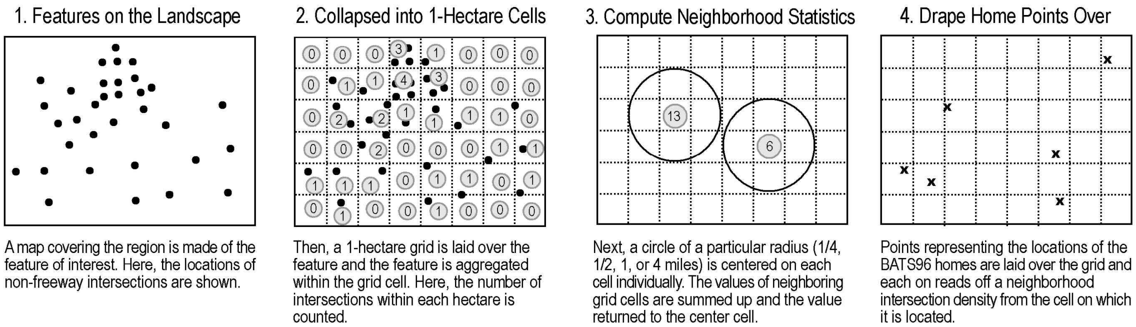
Correctly incorporating built-form characteristics into statistical models is a complicated undertaking. Some built-form characteristics such as density are fairly easy to measure, and secondary data are widely available. Other characteristics, such as building type and frontage diversity, are more difficult to make operational, and measurements must be taken first-hand. Most built-form characteristics (e.g., land use diversity, intersection density, average lot size, street widths) fall between these extremes; the limited secondary data that is available provides only a partial measurement of built-form and so must be carefully adapted to the issue at hand.

A second issue concerns scale. Spatial and built-form information has traditionally been incorporated into mode choice models by assigning to each trip-maker the average or typical built-form characteristics associated with their census tract or transportation analysis zone (TAZ) of residence. This approach has a number of limitations. Zonal measures of built-form may have little to do with actual place or neighborhood characteristics. Tract or zonal boundaries are rarely delineated in such a way as to account for distinct land uses, urban forms, or building types. Individuals who live near edges of TAZs are assigned the same built-form values as those who live near the center, regardless of the characteristics of neighboring zones. Most importantly, the scale at which information on the built environment is collected and analyzed may have little relevance to the spatial scale and context within which individual travel decisions are actually made.

This research uses the analytical power of geographic information systems (GIS) to develop measures of urban form at multiple scales. As shown in Figure 4, this process involves four steps. First, a feature of interest—for example, the location of every non-highway street intersection—is mapped over the entire study area (in this case, the entire Bay Area). Second, GIS is used to subdivide the region into smaller grid-cells or rasters, each of which is coded to the presence, absence, or count of the relevant spatial feature. The grid cells used in this analysis measure 100 meters on a side and have an area of one hectare (10,000 square meters) or about 2.5 acres.

Third, GIS is used to identify and summarize the built-form characteristics of a series of multiple "spatial neighborhoods" of increasing radius measured around each grid cell. Depending on the characteristic of interest, a spatial neighborhood can range in width from 100 meters (the width of a single grid cell) to four miles. Neighborhoods are typically square or circular in shape, but depending on the power and sophistication of the GIS system, can also be doughnut- or wedge-shaped. Neighborhood measurements may include counts, averages, maximum values, minimum values, majority and minority values, and diversity measures. The values of the resulting neighborhood metrics are then returned to the grid cell at their center. Fourth, the resulting grid-cell measurements are assigned to the home locations of all trip-makers whose addresses fall within each cell. Although extremely computation-intensive, this process makes it possible to assign spatial measurements of urban form to trip-maker locations at a variety of scales.

Figure 4: Cell-by-Cell Measurements



Although less ad hoc than the use of zonal averages, grid cell-based neighborhood measurements are not without their own complications. Unless the analyst is willing to test all possible combinations of neighborhood size and shape, they must rely on some *ex ante* notion of the appropriate neighborhood scale and configuration. The built-form measurements that follow are all based on circular "walking neighborhoods," ranging in radius from one-quarter mile to one mile.[6] Access measurements are developed for circular neighborhoods ranging in size from one-quarter mile to four miles.[7]

We considered nine measures of built-form, including population density, proximity to commercial development, the proportion of commercial land uses within each neighborhood, land use homogeneity, residential heterogeneity, block size, intersection density, parcel size, and visual heterogeneity. Figure 5 reports the average, range, and median value of each measurement across the full BATS96 sample.

Population Density is the built-form characteristic most closely associated with pedestrian and non-motorized trips. Following the literature, we would expect higher densities to be associated with a greater propensity to walk, bicycle, taxi, or use certain types of transit. Higher density neighborhoods, it is often presumed, are more likely to include a greater diversity of land uses and activities within easy walking distance of each other. Higher residential densities are typically associated with increases in retail and service variety, as local market areas are able to accommodate additional retailers. This in turn translates into shorter, walkable distances between complementary shops and restaurants. It is this combination of easy accessibility and increased variety that makes pedestrian neighborhoods seem more interesting. Driving and particularly parking are also likely to be more difficult and time-consuming in higher-density neighborhoods, adding to the relative attractiveness of walking and/or certain types of transit.

Density estimates were generated by dividing the number of residents per census block as reported in the 1990 Census, by the amount of residential land area per census block, as reported by the Association of Bay Area Governments. For the sample as a whole, the average residential density within the quarter-mile "neighborhood" (generated using the method discussed above) is 36.7 persons per hectare, or fifteen persons per acre (see Figure 6). This is fairly high by national standards, and it reflects the fact that most Bay Area residents, and thus most BATS96 respondents, live in urban locations.

In general, the larger the spatial neighborhood generated around each respondent, the lower its average density. Among half-mile neighborhoods, for example, the average residential density is 34.2 persons per hectare. Among four-mile neighborhoods, it is 17.3 persons per hectare. Regardless of neighborhood size, median densities were much lower than average densities. This suggests that many more BATS96 households live in moderate-density neighborhoods than in high-density ones. At 331.7 persons per hectare, or 132 persons per acre, the highest-density BATS96 quarter-mile neighborhood is located in downtown San Francisco.

Accessibility to Commercial Land Uses and Activities. Land use planners have long understood the critical contribution of commercial land uses, particularly retail land uses, to good urban form. More recently, transportation planners have observed the relationships between easy access to retail land uses and shopping trip frequency and mode choice. Put simply, people who live near multiple and diverse retail opportunities tend to make more frequent, more specialized, and shorter shopping trips—many by walking. At the opposite extreme, people who live farther away from retail opportunities are more likely to chain together multiple shopping destinations, and if they have a car available, use it.

We measured accessibility to commercial land uses in two ways. Making use of ABAG's 1995 land use inventory, we first measured the straight-line distance from each BATS96 respondent's home location to the closest hectare of commercial land use. On average, BATS96 respondents live .56 kilometers (or about .32 miles) from a commercial land use (see Figure 6). The median distance to the nearest commercial land use, however, is only .36 kilometers (or about .2 miles), suggesting that the typical respondent lives within easy walking distance of some type of commercial activity.

Second, making use of the same data and spatial relationships, we estimated the proportion of developed land in commercial use within a quarter-mile, half-mile, one-mile, and four-mile circular neighborhood around each BATS96 respondent's home location. The greater the share of the nearby neighborhood in commercial use, the greater the ease and potential utility of walking. Evaluated at the mean, commercial land uses account for just under ten percent of the land area within the quarter-mile neighborhood around each respondent's home. Evaluated at the median, however, commercial development accounts for just two percent of land uses within a quarter-mile. The difference between the mean and median values suggests that while some BATS96 respondents are essentially surrounded by commercial land uses, the vast majority live in neighborhoods with almost no commercial development.

Extending the neighborhood radius to a half-mile and then a mile does not much alter the average share of commercial land uses, but it does significantly increase the median share. At a four-mile neighborhood radius, the mean and median shares are essentially equal. Interpreting the distance and share measures together indicates that while many BATS96 respondents live near *some* commercial land use, the vast majority live in neighborhoods dominated by non-commercial development.

Land Use Heterogeneity. Land use planners and urban designers have long argued in favor of heterogeneous land uses, particularly at the neighborhood level. The more varied the land use mix, the thinking goes, the more varied and interesting the built-form, and thus the more conducive that form to non-auto trips. Following Cervero and Kockelman (1997), we measured land use heterogeneity using an index of dissimilarity which varies between -1 (indicating a completely homogeneous land use mix) and +1 (indicating a completely heterogeneous land use

mix). As before, land uses were measured at the one-hectare level using ABAG's 1995 land use inventory. All urban land uses were classified into one of four categories: residential, commercial, industrial, and open space.8 For the sample as a whole, the mean value of the dissimilarity index for adjacent grid-cells is only .18 while the median value is zero (see Figure 6). Mean and median index values rise with neighborhood size, indicating an increase in land use heterogeneity with increasing scale. For one-mile neighborhoods, the mean and median index values are both about .4, indicating a somewhat diverse mixture of land uses.
A second urban dissimilarity index was developed including residential, commercial and industrial uses, but omitting open space. As Figure 5 shows, at the same scale level, the mean and median values of the urban dissimilarity index are about half those of the more generalized index presented above

Housing Stock Diversity. By virtue of their larger lot sizes, street frontages and setbacks, neighborhoods dominated by single-family detached homes are presumed to be more conducive to car use and less conducive to walking. Neighborhoods composed solely of single-family homes are also more likely to be in the suburbs, where bus service is generally less available. The proportion of single-family detached homes in each neighborhood was calculated using 1990 Census data measured at the block level.

Unlike other measures of urban form, the proportion of detached single-family homes does not vary much with scale. For the sample as a whole, the mean proportion of detached homes is .57–.58, regardless of neighborhood size. The median proportion is likewise invariant at .62. The standard deviation, however, does decline with increasing scale, indicating that larger neighborhoods tend to be more residentially diverse.

Figure 5: Built-Form and Access Variables as Measured for BATS96 Respondent Homes

	Scale (radius)	Mean	Standard Deviation	Minimum	Maximum	Median
Density: Persons per hectare	¼ mi	36.7	39.5	0	331.7	25.7
(Source: 1990 Census)	½ mi	34.2	35.0	0	256.2	24.4
	1 mi	30.5	28.5	0	159.8	22.3
	4 mi	17.3	13.1	0.002	57.1	13.9
Proportion of commercial land	¼ mi	0.095	0.151	0	1	0.020
uses within neighborhood	½ mi	0.101	0.118	0	0.751	0.066
(Source: ABAG)	1 mi	0.100	0.091	0	0.553	0.078
	4 mi	0.063	0.030	0	0.190	0.066
Distance to Commercial (km)		0.567	0.658	0	11.043	0.361
Dissimilarity Index	Adj	0.176	0.229	0	1	0
(Source: ABAG)	¼ mi	0.276	0.226	0	0.980	0.225
	½ mi	0.363	0.221	0	0.990	0.320
	1 mi	0.434	0.203	0	0.998	0.399
Urban Dissimilarity Index	Adj	0.083	0.267	-1	1	0
(Source: ABAG)	¼ mi	0.150	0.250	-0.980	0.980	0.102
	½ mi	0192	0.252	-0.995	0.970	0.147
	1 mi	0.208	0.244	-0.999	0.964	0.173
Transit Access	¼ mi	1.918	1.283	0	5	1.551
	½ mi	1.896	1.243	0	5	1.609
	1 mi	1.844	1.182	0	4.729	1.606
Intersection Density	¼ mi	0.515	0.252	0	1.918	0.490
(Source: 1995 TIGER)	½ mi	0.471	0.230	0.005	1.635	0.452
	1 mi	0.424	0.215	0.003	1.177	0.400
Mean Block Size	¼ mi	366.566	1238.366	0.834	14723.12	15.647
(Source: TIGER)	½ mi	449.028	1296.179	1.200	14723.14	26.668
	1 mi	594.248	1444.107	1.504	14723.14	50.947
Mean Parcel Size	¼ mi	0.359	0.604	0.032	11.040	0.201
(Source: Assessor's records)	½ mi	0.373	0.539	0.031	9.000	0.245
	1 mi	0.393	0.523	0.060	10.560	0.286
Proportion Detached	¼ mi	0.573	0.302	0.001	1	0.615
(Source: 1990 Census)	½ mi	0.574	0.276	0.001	0.996	0.617
	1 mi	0.578	0.244	0.006	0.988	0.621
Median Year Built	¼ mi	1959.5	14.164	1939.0	1989.0	1959.8
(Source: 1990 Census)	½ mi	1959.7	13.450	1939.0	1989.0	1959.9
	1 mi	1960.1	12.557	1939.7	1989.0	1960.6

Average Block Size. Larger block sizes have been long associated with reduced land use and activity variety. In terms of travel behavior, smaller blocks are more easily navigated by pedestrians. Block dimensions and areas were calculated using the 1995 Census TIGER file.[9]

Block size varies widely with location: block sizes are smaller in older cities, larger in communities, and huge at the urban edge. They also vary with scale, as Figure 6 shows. For the sample as a whole, the average block size is 367 hectares for quarter-mile neighborhoods, 450 hectares for half-mile neighborhoods, and 594 hectares for one-mile neighborhoods. Median block sizes, which are more indicative of urban form than average block sizes, are much smaller, but they too vary with scale. Evaluated at the quarter-mile neighborhood scale, the median block size for the sample as a whole is 15.6 hectares, or about 38 acres. At the one-mile scale, the median block size is 51 hectares, or about 126 acres.

Intersection Density. Block size is inversely related to intersection density. The bigger the average block, the fewer the number of street intersections that fit in a given area. The relationship between intersection density—which is calculated as the number of street intersections per square kilometer—and travel behavior is a complicated one. All else being equal, the more intersections there are, the greater the number of streets that must be crossed and the larger the number of traffic lights and stop signs. Traffic lights and stop signs slow all travel, not just car travel. Proportional to total travel time, however, the slow-down effect is far greater for cars than pedestrians. Higher intersection densities are also correlated with increased network connectivity, thus providing travelers with a greater variety of potential routes. The advantages of increased network connectivity are also a matter of scale. At the eighth-, quarter- or half-mile scale, the advantages of increased connectivity accrue principally to pedestrians. At the one-mile or greater scale, they accrue to drivers.

Average Parcel Size. Parcel size, like block size, is mostly a matter of location. Parcels in older urban jurisdictions tend to be smaller than those in newer communities, partly as a function of when they were developed and partly because of higher land values. Smaller parcel sizes, like smaller block sizes, are associated with a more variegated urban form and a greater diversity of structure and building types. Blocks composed of smaller parcels are also likely to be more visually interesting, especially to pedestrians.

Average and median parcel sizes vary only slightly with scale. For the full sample of BATS96 respondents, the average parcel size for quarter-mile, half-mile, and one-mile neighborhoods is about the same: .4 hectares, or about 1 acre (see Figure 6). At .2 to .3 hectares, depending on the scale, median parcel sizes are a good bit smaller.

Visual Heterogeneity. The more visually heterogeneous and interesting a trip, the more travelers will want to take their time—that is, to walk. Visual homogeneity, by contrast, makes the experience of traveling, especially by foot, a more utilitarian and less interesting experience. The preferred approach to measuring visual heterogeneity is onsite inspection. Alternatively, visual heterogeneity can be measured through the use of three-dimensional representations such as photographs and movies. It cannot be easily measured using numerical census data or even two-dimensional maps. For large samples, such as BATS96, comprehensively evaluating visual heterogeneity is simply out of the question.

Fortunately, building age is a pretty good proxy measure of visual heterogeneity. Both for market and regulatory reasons, new buildings of all types are growing far more similar than they used to be. High land prices, zoning and subdivision ordinances, and a preference for mass production are rendering new subdivisions more and more alike. Office and industrial park buildings are mostly cut from the same cloth, as are just about all new big-box retail centers. Where regions and even cities once had their own distinct architecture, today's housing subdivisions, suburban office parks and retail centers are pretty much indistinguishable regardless of location. While no agency comprehensively collects information on the age distribution of commercial buildings, the Census Bureau, as part of the dicennial census does collect information on housing stock age. For the BATS96 sample as a whole, the average or typical home within a quarter-mile neighborhood was built between 1950 and 1960. Home ages—or vintages, as they are more commonly known—tend to vary at the regional and sub-regional scales, but not at the neighborhood scale. As Figure 6 shows, the age distribution of Bay Area homes is roughly the same at the quarter-mile, half-mile and one-mile neighborhood scales. All else being equal, we would expect older subdivisions and neighborhoods to be more visually interesting—and thus supportive of pedestrian travel—than newer ones.

Transit Supply and Trip Characteristics

Demographic and built-form characteristics are not the only factors that affect mode choice; trip cost and convenience also play a huge role. For trips more than a quarter-mile in length, travelers tend to prefer cars to transit and transit to walking for reasons of speed, convenience, and protection from the elements. Traditional travel demand forecasting models predict mode choice by comparing the time and monetary cost of all competing modes for all trip possibilities and purposes. Lacking the resources for such an approach, we chose instead to focus on the accessibility and availability of mass transit service.

All else being equal, especially car ownership, we expect people living in places with high levels of public transit service to make greater use of transit, particularly for non-work trips. As a measure of transit service quality, we created a TAZ-based generalized transit access index (GTAI) that varies between 0 and 5. Locations receiving a GTAI value of 0 have no regular transit service. Locations receiving a 5 are served by multiple transit agencies running many routes with per-route frequencies in the 5 to 15 minute range. The limited bus service provided by most suburban transit agencies earned a GTAI rating of 1 or 2, while locations served by BART, MUNI, and VTA earned a GTAI rating of 3 or 4, depending on the number and frequency of bus connections.

GTAI values vary widely by location but not neighborhood size or scale.[10] The average GTAI value for the BATS96 sample as a whole is 1.9 regardless of neighborhood size. The median GTAI value of 1.6 is similarly invariant to neighborhood scale.

In addition to socio-demographic and built-form characteristics, the mode choice models that follow also include control variables measuring the characteristics of the trips themselves. These include trip length or distance (*DISTANCE*) and trip day (*DV_WEEKEND*). As trip lengths increase, travelers are expected to be more likely to prefer more flexible and higher-speed modes to walking. Conversely, weekend trip-makers may be more likely to walk because their time is more flexible and because walking is seen by many as a leisure activity. Last, weekend trip-makers may be less likely to use transit because of reduced opportunities for work trip-based trip-chaining.

Prototypical Neighborhoods

The multiple characteristics that comprise the built environment are not easily separated. High-density urban neighborhoods are typically composed of smaller parcels and blocks and also boast a greater variety of land uses and activities. Lower density suburban neighborhoods, on the other hand, are typically comprised of larger blocks and parcels and are more homogeneous with respect to land use and building type. (In the language of statistics, built-form characteristics are highly correlated with each other.) Before considering the separable effects of different built-form characteristics on non-work mode choice, it is worth considering how they typically combine.

To do so, we looked at the combination of built-form measures in six archetypal Bay Area neighborhoods (Figure 6). Arranged in order of residential density, the six are: Nob Hill in San Francisco, Noe Valley in San Francisco, Downtown San Jose, Rockridge in Oakland, Concord, and South San Jose. The following sections discuss each neighborhood individually.

Nob Hill is one of the most urban neighborhoods in America—the San Francisco of six-story apartment buildings and cable cars. Its sample point is in the midst of an incredibly dense neighborhood with virtually no detached housing. Land uses are mixed at larger scales, but the immediate neighborhood is more homogenously residential. A fine-grained street system results in a high intersection density and small blocks, however, parcel sizes are relatively large since they are almost all used for apartment buildings.[11]

Noe Valley is an upscale San Francisco neighborhood, located two miles south of downtown San Francisco and consisting largely of older attached and detached homes. Noe Valley's density is a third of Nob Hill's. About one-fifth of Noe Valley homes are detached. Commercial uses are limited to major street frontages. Most buildings are less than three stories in height.

Rockridge is a neighborhood in northern Oakland that developed around a streetcar stop almost a century ago and is now considered a place to emulate by many neo-traditionalists. Although its population density is only 1/2 to 1/3 of Noe Valley's, Rockridge land uses are highly mixed, and retail uses are a short walk away. Rockridge's larger blocks and lower intersection densities (compared to Noe Valley and Nob Hill) are typical of early 20th Century suburbs.

The sample location in Concord is typical of suburban development from the 1950s and 1960s. Concord densities are much lower than those in San Francisco and Oakland neighborhoods. Few commercial land uses intrude into residential neighborhoods. Block and parcels sizes are large and unvaried.

The Downtown San Jose sample location is in an area developed in the 19th Century as the center of a small agricultural town, but that was bypassed by later commercial development when San Jose became a major city. Densities are similar to those of Rockridge, but there is less land use mix (particularly at smaller scales) and a much greater separation between residential and commercial land uses.

The South San Jose location is typical of more recent high-end suburban neighborhoods with large blocks, very low residential densities and extreme land use separation.

Figure 6: Built-Form Characteristics of Six Bay Area Neighborhoods

	Nob Hill, SF	Noe Valley, SF	Rockridge	Concord	Downtown San Jose	South San Jose
Persons per Hectare	253.2	87.4	39.3	15.7	60.5	2.0
Proportion Commercial	0.02	0.02	0.29	0.00	0.00	0.00
Avg. Distance to Commercial Development (km)	0.30	0.22	0.10	1.08	0.54	0.89
Dissimilarity Index	0.250 0.082	0 0.041	0.375 0.490	0 0.143	0 0	0.750 0.776
Urban Dissimilarity Index	0.250 0.082	0 0.041	0.375 0.347	0 0	0 0	0 0
Transit Access	4.551	3.735	3.327	1	2	1
Intersection Density	1.163	0.612	0.551	0.469	0.408	0.163
Mean Block Size	1.39	1.75	4.43	65.49	2.68	1807.6
Mean Parcel Size	0.331	0.066	0.159	0.207	0.138	0.352
Proportion Detached	0.009	0.216	0.630	0.512	0.511	0.869
Median Year Built	1939	1939	1939	1978	1942	1985

Note: These measurements are from a single sample point picked to be representative of the typical built form in that neighborhood.

MODEL RESULTS AND INTERPRETATION

Four sets of mode choice models were tested in total: one set for *all* home-based non-work trips regardless of purpose; one set for home-based shopping trips; one set for home-based entertainment trips; and one set for home-based transit access trips. Each model set consists of four equations: (i) a *base* model which includes all respondent socio-demographic characteristics; (ii) a *parsimonious* model, which includes only the demographic characteristics that are statistically significant; (iii) an *expanded-base* model, which adds all the built-form characteristics to the base model; and, (iv) an *expanded-parsimonious* model, which includes only those variables from the expanded model found to be statistically significant. All models were tested using multinomial logistic regression. For simplicity's sake, the results and discussions that follow focus only on the parsimonious and expanded-parsimonious models.

All (Home-Based) Non-Work Purposes Combined

This analysis combines shopping trips, school trips, and social and recreational trips. Altogether, the full sample of BATS96 respondents undertook 7,605 home-based non-work trips.

Results of the parsimonious and expanded-parsimonious models are shown in Figure 7. The various mode choice combinations were collapsed into three dominant mode choices: driving, transit, and walking. Two parameter estimates are reported for each independent variable—one for walking and one for transit use. Driving was intentionally excluded to guarantee a unique solution. Standard errors are not reported; asterisks are used to indicate significance levels. Odds-ratios, which indicate the effect of a unit change in the value of the independent variable on the probability of choosing a particular mode are reported. Odds-ratio values less than one indicate that a variable has the effect of reducing the probability of choosing a particular mode, while odds-ratios greater than one indicate an increased probability.

With respect to the base model, almost all the included socio-demographic variables are statistically significant and have effects in the expected directions. The likelihood of walking or taking transit decreases with age—every ten years of additional age reduces the likelihood of walking or using transit by about 15%. Members of larger households are less likely to walk or use transit than members of single- or two-person households. African-Americans are more likely to take transit but less likely to walk while Asian-Americans are twice as likely to use transit. Individuals possessing a driver's license are 50 times less likely to walk or take transit. Employed individuals are two-and-a-half times more likely to take transit but are indifferent to walking. Full-time students are almost two times more likely to take transit, but are also indifferent to walking. Members of well-off households—those making more than $100,000 per year—are about 15% more likely to take transit but about 80% less likely to walk as compared to members of poorer households—those making $30,000 to $35,000 per year. The availability of an additional auto per licensed household driver makes either walking or transit use about four times less likely. Homeowners are half as likely to walk or use transit as renters. Finally, trips made on the weekend are 20 percent less likely to be walking trips and 33% less likely to be transit trips than comparable trips made on weekdays.

The consistency of these results notwithstanding, overall, the basic model does a poor job predicting non-work mode choice decisions. The basic model's pseudo r-squared, a measure of overall goodness-of-fit, is only .185. Although disappointing, these results are not unexpected. Indeed, they are somewhat better than the results of other similar studies. Discretionary trips are by their very nature discretionary. Lumping multiple trip purposes into a single model also reduces overall model reliability.

The expanded model, which includes four measures of built-form, performs only slightly better.[12] The G-statistic, which is similar to an F-statistic for multiple regression, indicates an improvement in overall model reliability, and the pseudo r-squared rises to .237. The parameter values and significance levels of the socio-demographic variables change only slightly with the addition of the built-form variables. The greatest change is in the effect of owning one's home, a factor highly correlated with lower-density detached-unit neighborhoods.

Each of the built-form variables is significant and their effects, although modest, are in the expected directions. An increase in average density of ten persons per hectare (about four persons per acre) within one mile of an individual's residence is associated with a 7% increase in the probability of walking or of taking transit. For every kilometer reduction in distance to the nearest commercial land use larger than one hectare, the probability of walking goes up 42% while the likelihood of using transit decreases by 30%. This suggests that for many non-work trips, the critical trade-off is between walking and using transit, not car use and transit, or car use and walking. Residential diversity also matters: as the proportion of detached homes within a quarter-mile decreases from 0.5 to 0.25, the probability of walking increases by about 40% and the probability of taking transit increases about by a quarter. Neighborhood age matters too: controlling for both density and housing variety, residents who live in older areas are much more likely to walk and somewhat more likely to use transit.

Figure 7: Multinomial Mode-Choice Model for All Home-Based Non-Work Trips

		Base-Parsimonious Model			Expanded-Parsimonious Model		
		Coefficient		**Odds Ratio**	**Coefficient**		**Odds Ratio**
Age	(w)	-0.017	***	0.984	-0.013	***	0.988
	(t)	-0.014	**	0.986	-0.012	**	0.988
DV_Licensed	(w)	-3.852	***	0.021	-3.589	***	0.028
	(t)	-3.954	***	0.019	-3.739	***	0.024
DV_Full-Time Student	(w)	-0.006		0.994	-0.006		0.994
	(t)	0.614	***	1.848	0.610	***	1.840
DV_Employed	(w)	0.143		1.154	0.015		1.016
	(t)	0.900	***	2.459	0.856	***	2.353
DV_African American	(w)	-0.291	*	0.748	-0.377	**	0.686
	(t)	0.385		1.470	0.357		1.429
DV_Asian American	(w)	-0.004		0.996	-0.159		0.853
	(t)	0.728	***	2.072	0.647	***	1.429
Household Size	(w)	-0.368	***	0.692	-0.209	***	0.812
	(t)	-0.358	***	0.699	-0.249	***	0.779
Household Income	(w)	-0.032	***	0.968	-0.035	***	0.966
	(t)	0.039	*	1.039	0.031		1.031
Vehicles/License	(w)	-1.431	***	0.239	-1.014	***	0.363
	(t)	-1.506	***	0.222	-1.241	***	0.289
DV_Own Home	(w)	-0.784	***	0.457	-0.357	***	0.699
	(t)	-0.659	***	0.517	-0.444	***	0.642
DV_Weekend Trip	(w)	-0.326	***	0.722	-0.368	***	0.692
	(t)	-1.102	***	0.332	-1.140	***	0.320
Km to Commercial	(w)				-0.325	***	0.723
	(t)				0.354	***	1.425
Pop. Density within 1mi	(w)				0.006	***	1.006
	(t)				0.007	**	1.007
Med Yr Housing Hmi	(w)				-0.028	***	0.973
	(t)				-0.017	***	0.984
PropDet Housing 1mi	(w)				-1.413	***	0.243
	(t)				-0.891	**	0.410
Intercept	(w)	5.856			59.107		
	(t)	3.124			34.827		
-2 Log Likelihood		7207.422		8842.292	6765.842		
R^2		0.185			0.237		
N		7604			7604		

*** significant at $\alpha = 0.01$
** significant at $\alpha = 0.05$
* significant at $\alpha = 0.1$

Many built-form variables did not make it into the expanded model. The proportion of commercial land uses, the two dissimilarity indices, intersection density, and average block and parcel size were all either statistically insignificant, or else highly correlated with the built-form variables that were included. The generalized transit access index (GTAI), although included, was statistically insignificant.

The modest success of our attempt to fit a single model of all home-based non-work trips suggests that it might be more appropriate to estimate separate models for specific trip purposes. BATS96 contains dozens of trip purposes, most of which have few recorded trips. The sections that follow develop models for the three most plentiful trip categories: shopping, entertainment, and transit access.

Home-Based Shopping Trips

The BATS96 survey contains roughly six thousand home-based trips with the purpose of shopping, doing errands, or beginning a tour of errands (henceforth referred to simply as "shopping"). Of these, around 650 were walking trips and around 210 were transit trips. Results of the base-parsimonious and expanded-parsimonious models are shown in Figure 8. Surprisingly, the pseudo r-squared measures for the base and expanded shopping trip models were lower than their counterparts for the broader set of non-work trips models discussed above.

The fewer number of observations results in a more parsimonious model with fewer independent variables than in the all-purpose model. Having a driver's license, being employed, household size, household income, and owning one's home affect shopping trip mode-choice in the same fashion as in the all-purpose model. The number of vehicles per licensed driver has less of an effect on the probability of taking a walk trip than in the all-purpose model.

The addition of the built-form and transit access variables improved the fit of the model only slightly. A one-point increase in the five-point generalized transit accessibility index (GTAI) increased the likelihood of a transit trip for shopping by a third and raised the probability of a walk trip by over 20%. Shopping trip-makers living in older neighborhoods, as measured by the median year of housing construction, were 31% more likely to walk and 21% more likely to take transit. Residential building diversity also matters. Trip-makers living in quarter-mile neighborhoods in which detached homes accounted for only a quarter of the housing stock—instead of the more typical half—were more than a third more likely to use transit and 20% more likely to walk.

Surprisingly, neither population density, nor the proportion of commercial land uses within the neighborhood, nor distance to the nearest commercial land use, nor the two measures of land use heterogeneity significantly affected walk and transit mode choice probabilities. Taken together, the combination of mediocre model fit and un-entered variables suggests that most shoppers make their mode choice decisions on the basis of travel cost and convenience—none of which were explicitly included in the models—rather than on the basis of the physical nearness to shopping opportunities or built-form.

Figure 8: Multinomial Model of Home-Based Shopping and Multipurpose Trips

		Base-Parsimonious Model			Expanded-Parsimonious Model		
		Coefficient		Odds Ratio	Coefficient		Odds Ratio
Licensed	(w)	-3.764	***	0.023	-3.553	***	0.029
	(t)	-4.063	***	0.017	-3.867	***	0.021
DV_Employed	(w)	0.274	***	1.315	0.125		1.134
	(t)	1.089	***	2.970	0.992	***	2.696
Household Size	(w)	-0.293	***	0.746	-0.163	***	0.850
	(t)	-0.351	***	0.704	-0.246	***	0.782
Household Income	(w)	-0.043	***	0.958	-0.048	***	0.953
	(t)	0.035		1.036	0.026		1.027
DV_Own Home	(w)	-0.978	***	0.376	-0.593	***	0.553
	(t)	-0.790	***	0.454	-0.423	**	0.655
Vehicles/License	(w)	-1.334	***	0.263	-0.944	***	0.389
	(t)	-1.506	***	0.222	-1.174	***	0.309
Transit Access-Qmi	(w)				0.211	***	1.235
	(t)				0.282	***	1.326
MdYr Built-Qmi	(w)				-0.027	***	0.973
	(t)				-0.02		0.998
Pdet Qmi	(w)				-0.712	***	0.491
	(t)				-0.681	*	0.506
Intercept	(w)	4.483			55.945		
	(t)	2.453			5.692		
-2 Log Likelihood		4854.794		5734.084	4628.908		
R^2		0.153			0.193		
N		5927			5927		
G Statistic					225.886		sig< 0.0001

*** significant at $\alpha = 0.01$
** significant at $\alpha = 0.05$
* significant at $\alpha = 0.1$

Home-Based Entertainment Trips

The BATS96 dataset contains over one thousand home-based *entertainment* trips, 157 by walking and 51 by transit. Results of the base and expanded models are shown in Figure 9. The entertainment trip mode choice models fit the observed data even less well than the shopping trip models. For the base model, the pseudo r-squared measure is only .11; for the expanded model, it is .16.

Only four socio-demographic variables enter the base-parsimonious model: having a driver's license, being employed, household income, and the number of vehicles per driver's license. Having a driver's license overwhelmingly reduces the likelihood that a traveler will walk or use transit—by 95% in the case of walking and by 98% for transit. Being employed makes transit trips more likely but walking trips less likely. The more vehicles available per licensed driver, the less likely a traveler is to walk or take transit. All else being equal, members of upper income households are less likely to use transit for entertainment trips than members of low- and middle-income households.

The addition of the three most significant built-form variables—the quarter-mile urban dissimilarity index (UDI), the average quarter-mile intersection density, and the proportion of detached homes within a quarter mile—improves the model results only slightly. Although minor, the effects of the built-form variables are as expected. Residents of neighborhoods with a diversity of nearby land uses are far more likely to walk to entertainment. (On a scale of 0 to 1, a 0.25 increase in UDI value increases the likelihood of a pedestrian trip by nearly 50%). Higher intersection densities encourage both walk and transit trips. For example, a .25 increase in intersection density (the difference between suburban Concord and central Palo Alto) increases the probability of walking by 45% and the probability of taking transit by 62%. With increasing intersection density comes increasing traffic congestion and parking difficulties. This makes car use much less attractive than walking or taking the bus. Residents of neighborhoods dominated by single-family homes are also far more likely to walk or take transit for their entertainment trips, even holding density constant. Neither neighborhood population density nor the availability of transit service affects the likelihood that an individual will make their entertainment trips by walking or transit.

Figure 9: Multinomial Logit Mode Choice Model of Home-Based Entertainment Trips

*** significant at α = 0.0
** significant at α = 0.05

		Base-Parsimonious Model			Expanded-Parsimonious Model		
		Coefficient		**Odds Ratio**	**Coefficient**		**Odds Ratio**
DV_ Licensed	(w)	-2.957	***	0.052	-2.815	***	0.060
	(t)	-3.985	***	0.019	-3.923	***	0.020
DV_Employed	(w)	-0.427	**	0.652	-0.743	***	0.476
	(t)	1.071	***	2.918	0.672	*	1.959
Household Income	(w)	-0.067	***	0.935	-0.012		0.988
	(t)	-0.025		0.975	0.018		1.018
Vehicles/License	(w)	-0.397	*	0.673	-0.188		0.828
	(t)	-1.730	***	0.177	-1.283	***	0.277
UDI Qmi	(w)				0.768	*	2.156
	(t)				-1.075		0.341
IntD Qmi	(w)				1.500	***	4.482
	(t)				1.940	***	6.958
PDet Qmi	(w)				-1.267	***	0.282
	(t)				-1.5	**	0.223
Intercept	(w)	2.413			1.467		
	(t)	2.038			1.284		
-2 Log Likelihood		1133.444		1277.596	1071.094		
R^2		0.113			0.162		
N		1067			1067		
G Statistic							sig< 0.0001

* significant at α = 0.1

Home-Based Transit Access Trips

Trips made for the purpose of accessing a rapid transit train, usually BART or MUNI, demonstrated a fair amount of patterning. Overall, the BATS96 dataset included 610 such trips, of which 387 were walking trips and fewer than 50 were by bus transit. Results of the base and expanded-parsimonious models are shown in Figure 10. Although mediocre by conventional standards—the pseudo r-squared statistics are .18 for the base model and .38 for the expanded model—the model does fit the observed data better than the shopping or entertainment mode choice models discussed above.

As with the entertainment trip models, having a driver's license and the number of available vehicles per driver license in a household are the two most important determinants of mode choice. Travelers with driver's licenses are 95% less likely to walk or take a bus to a BART or MUNI station. The effects of auto availability are almost as great. Wealthier travelers are also less likely to walk or take the bus to a rail transit stop. On the positive side, full-time students, who are also less likely to own cars, are over three times more likely to walk to rail transit and over four times more likely to take the bus.

The expanded model for transit access trips performed better than any other model tested. The addition of neighborhood median year of construction, the proportion of detached housing in the vicinity, and the generalized transit access index (GTAI)—all measured at the quarter-mile scale—increased the pseudo r-squared to 0.38. The improvement in goodness-of-fit between the base and expanded models was also largest for the transit access model. Of the three added measures, GTAI was the most important. An increase of 1 on the one-to-five GTAI scale was associated with a doubling of the likelihood of walking and a 75% increase in the use of bus transit. Holding density constant, residents of older neighborhoods were also more likely to walk to the nearest rail station, but not necessarily take the bus. Lastly, the greater the diversity of housing types in a neighborhood, the more likely residents were to walk to the nearest transit station. As with shopping and entertainment trips, density by itself did not affect the choice of access mode.

Figure 10: Multinomial Logit Mode Choice Model of Home-Based Transit Access Trips

		Base-Parsimonious Model			Expanded-Parsimonious Model		
		Coefficient		**Odds Ratio**	**Coefficient**		**Odds Ratio**
Household Income	(w)	-0.188	***	0.829	-0.040		0.960
	(t)	-0.122	**	0.885	-0.008		0.992
DV_Licensed	(w)	-3.034	***	0.048	-3.257	***	0.038
	(t)	-3.185	***	0.041	-3.322	***	0.036
Vehicles/License	(w)	-1.901	***	0.149	-1.279	***	0.278
	(t)	-1.883	***	0.152	-1.767	***	0.171
DV_Fulltime Student	(w)	1.287	***	3.621	1.914	***	6.778
	(t)	1.526	**	4.601	2.046	***	7.737
Median Year Qmi	(w)				-0.044	***	0.957
	(t)				-0.020		0.980
Prop. Detached Qmi	(w)				-2.324	***	0.098
	(t)				-0.250		0.779
Transit Access Qmi	(w)				0.662	***	1.939
	(t)				0.569	**	1.767
Intercept	(w)	7.042			90.069		
Intercept	(t)	4.412			40.999		
-2 Log Likelihood		871.244		1061.612	656.840		
R^2		0.179			0.381		
N		610			610		
G Statistic							sig< 0.0001

*** significant at α = 0.01
** significant at α = 0.05
* significant at α = 0.1

Residual Tests

Although the expanded models were built with hopes of uncovering the appropriate scale at which to investigate the environmental influence on travel behavior, the majority of the physical measurements proved redundant and added little to model performance. Figure 11 shows some of the results of this investigation by listing correlation coefficients between the residuals generated by the base model (for all trip purposes) and the built-form factors measured at different scales. With respect to both walking trip and transit trip residuals, the various built-form correlation coefficients and their respective significance levels do not vary with increasing spatial neighborhood scale. Since, as shown earlier, the built-form characteristics themselves *do* vary with scale, this suggests that the effects of built-form on mode choice are not subject to clear threshold effects. Put another way, the effects of the land use mix or intersection density or average block size on non-work mode choice are not significantly different whether measured at a ¼-mile, ½-mile, or one-mile neighborhood scale.

Figure 11: Correlation Between Model Residuals and Built-Form Factors

		Walking Residual		Transit Residual	
	Scale	**R**	**Sig.**	**R**	**Sig.**
Persons per Hectare	¼ mi	0.184	0.0001	0.111	0.0001
	½ mi	0.193	0.0001	0.103	0.0001
	1 mi	0.201	0.0001	0.101	0.0001
	4 mi	0.195	0.0001	0.108	0.0001
Proportion Commercial	¼ mi	0.068	0.0001	-0.011	0.3894
	½ mi	0.071	0.0001	-0.003	0.7856
	1 mi	0.066	0.0001	0.005	0.6818
	4 mi	0.055	0.0001	0.005	0.6714
Distance to Commercial (km)		-0.070	0.0001	0.001	0.9428
Dissimilarity Index	Adj.	0.016	0.1764	-0.027	0.0274
	¼ mi	0.010	0.4029	-0.008	0.5007
	½ mi	-0.013	0.2799	-0.024	0.0560
	1 mi	-0.025	0.0295	-0.014	0.2459
Urban Dissimilarity Index	adj	0.027	0.0207	-0.036	0.0038
	¼ mi	0.026	0.0290	-0.012	0.3206
	½ mi	0.019	0.1090	-0.023	0.0644
	1 mi	0.020	0.0918	-0.020	0.1137
Transit Access	¼ mi	0.198	0.0001	0.097	0.0001
	½ mi	0.200	0.0001	0.099	0.0001
	1 mi	0.201	0.0001	0.100	0.0001
Intersection Density	¼ mi	0.132	0.0001	0.060	0.0001
	½ mi	0.153	0.0001	0.069	0.0001
	1 mi	0.168	0.0001	0.069	0.0001
Mean Block Size	¼ mi	-0.038	0.0010	-.0004	0.9705
	½ mi	-0.049	0.0001	0.010	0.4389
	1 mi	-0.059	0.0001	0.004	0.7457
Mean Parcel Size	¼ mi	-0.051	0.0001	-0.027	0.0285
	½ mi	-0.063	0.0001	-0.039	0.0020
	1 mi	-0.063	0.0001	-0.030	0.0166
Proportion Detached	¼ mi	-0.137	0.0001	-0.066	0.0001
	½ mi	-0.152	0.0001	-0.072	0.0001
	1 mi	-0.174	0.0001	-0.078	0.0001
Median Year Built	¼ mi	-0.165	0.0001	-0.050	0.0001
	½ mi	-0.167	0.0001	-0.053	0.0001
	1 mi	-0.165	0.0001	-0.052	0.0001

Interpretations

The results of the various statistical models can be difficult, not to say tedious, to interpret. Clearly, the expanded models provide more comprehensive explanations of travel behavior than do the base models. This suggests that built-form does indeed matter. Even so, the best of the expanded models explains less than half of the observed variability in individual mode choice decisions. Based on the variables that seem to matter most, there is also some reason to suspect that what is really going on is a pattern of residential sorting whereby those types of travelers who choose to live in diverse and dense neighborhoods are ones who are predisposed to walking and taking transit. These reservations aside, we now consider the cumulative effects of built-form considerations on individual mode choice decisions.

We do this in two ways. The first is to let individual built-form characteristics vary over a continuum, holding constant other built-form and socio-demographic considerations. The second is to simulate the mode choice decisions and resulting mode splits of typical travelers living in a variety of actual neighborhoods. By typical, we mean travelers having the average or typical socioeconomic characteristics. This is not to assign particular individuals or types of individuals to particular neighborhoods. Rather, it is simply a mechanism for considering how population and household characteristics, built-form, and mode choice all co-vary.

Partial Probability Curves. Measured using partial probability curves (which evaluate the effects of changes in a single variable on travel mode choice, assuming all other variables take on their average values), the relationships between built-form and the probability of a particular mode choice are modest. As seen in Figure 12 an increase in population density, from the sample minimum value of just over zero persons per hectare to the sample maximum value of 330 persons per hectare, is associated with an increase in the probability of taking transit (for any non-work trip) from around 0.02 to just over 0.10. The same increase in density increases the probability of walking from just under 0.10 to around 0.22. Increasing distances to non-residential land uses have the opposite effect: as the distance to the closest commercial site increases from a sample minimum of zero to a sample maximum of six kilometers, the probability of walking falls from around 0.12 to 0.02, while the probability of taking transit increases from around 0.02 to 0.15 (Figure 12). Moving the range of the median age of the housing stock in the neighborhood from 1939 to 1989 (the range of the census-based data) leads the probability of walking to drop from around 0.17 to under 0.05, while the probability of using transit drops just a little, from 0.03 to 0.02. Finally, as the proportion of detached housing in the neighborhood increases from 0 to 1, the probability of walking drops from around 0.22 to 0.06, while transit again sees less change, moving from 0.04 to 0.03.

What of the cumulative effects of these individual factors? As Figure 13 shows, changing the values of all the important built-form variables at the same time and in the same direction increases the likelihood of walking from 0 to .35 and the likelihood of using transit from. 0 to .25. Both curves, however, are non-linear, suggesting that significant cumulative change to neighborhood built-forms are required in order to boost walking or transit use.

Archetypal Neighborhoods. Another approach to looking at built-forms is to evaluate the comparative effects of socio-demographic and built-form characteristics on traveler behavior in actual neighborhoods. Using the coefficients of the expanded-parsimonious model of all non-work trips, the probabilities of walking and taking transit were calculated for six types of demographically representative travelers living in five of the six archetypal neighborhoods previously profiled; the results of these calculations are presented in Figure 14. Note that all the generalizations that follow about the effects of socio-demographic and built-form characteristics apply only to non-work trips.

Figure 12: Component Impacts of Built-Form on Mode Choice

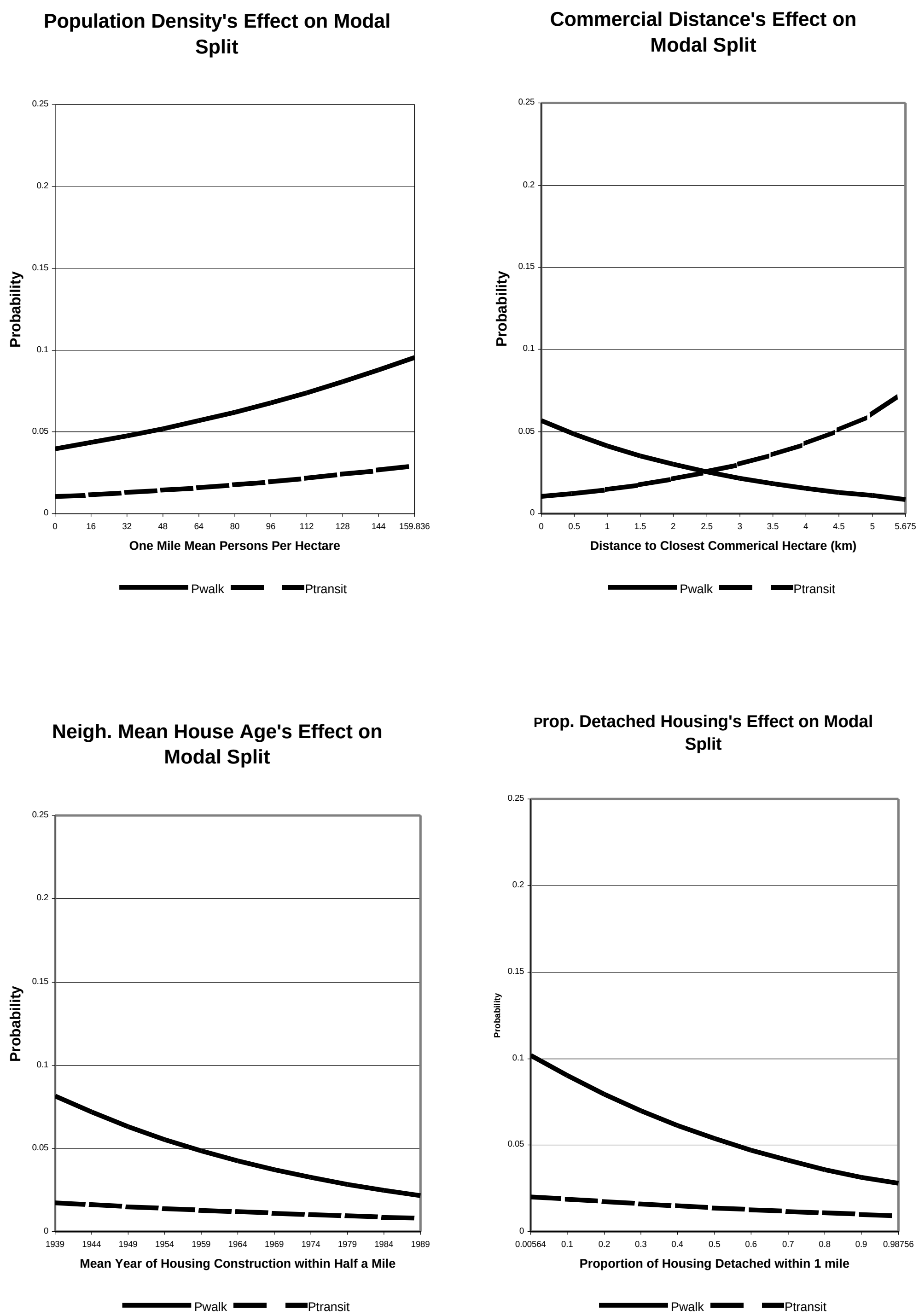


Figure 13 Overall Impacts of Built-Form on Mode Choice

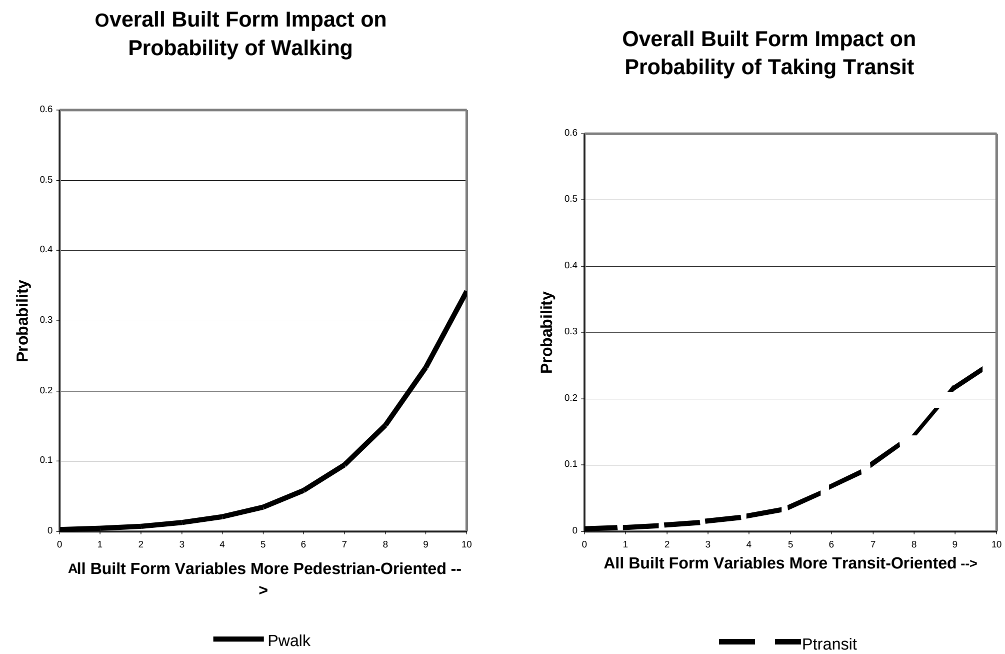


Figure 14 Predicted Mode Choice Probability of Six Simulated People Across Eight Bay Area Neighborhoods

		Nob Hill	Noe Valley	Rock-ridge	DT San Jose	S. San Jose
Wealthy Mother	P_w	0.29	0.11	0.05	0.06	0.01
	P_t	0.08	0.03	0.01	0.02	0.01
Professional Single Male	P_w	0.49	0.26	0.14	0.16	0.02
	P_t	0.15	0.07	0.04	0.06	0.02
Poor Black Male, w/o License	P_w	0.84	0.84	0.81	0.78	0.48
	P_t	0.15	0.14	0.14	0.18	0.26
Poor API with car	P_w	0.57	0.36	0.21	0.23	0.03
	P_t	0.18	0.10	0.06	0.09	0.03
White Student w/o car	P_w	0.77	0.60	0.42	0.44	0.08
	P_t	0.11	0.08	0.06	0.08	0.04
Poor Mom w/ shared car	P_w	0.55	0.29	0.15	0.17	0.02
	P_t	0.09	0.04	0.03	0.04	0.01

One out of three non-work trips taken by an **upper-income mother** living in San Francisco's Nob Hill neighborhood would be by walking; one out of ten would be by transit. The Nob Hill mom would be twice as likely to walk to shopping or entertainment than if she lived in the somewhat lower-density Noe Valley neighborhood, and 30 times more likely to walk than if she lived in the very low-density South San Jose neighborhood. Only the Nob Hill mom would take transit in any significant proportion.

One out of two non-work trips taken by a **single, white male professional worker** living in San Francisco's Nob Hill neighborhood would be via walking; one out of six would be via transit. Compared to a similar Noe Valley professional, the Nob Hill worker would be twice as likely to walk to shopping or entertainment. Similar workers living in South San Jose would walk only 1 out of 50 times. Compared to their Nob Hill counterparts, male professional workers living in Noe Valley would use transit less than half as much, while young professionals living in South San Jose would almost never use transit.

More than three-quarters of non-work trips taken by a **low-income, car-less African American male** would be via walking, whether they lived in Nob Hill, Noe Valley, Rockridge, or Downtown San Jose. Even in low-density South San Jose, one out of two non-work-tips taken by poor African American males would be via walking. The percentage of non-work trips taken via transit would range from a low of 14%–18% in the San Francisco and Oakland neighborhoods to a high of 26% in South San Jose.

Illustrating the power of a driver's license, a **low-income Asian Pacific Islander male** resident of any of the five profiled neighborhoods *with* a driver's license would be much less likely to walk than an otherwise similar African American *without* a driver's license. They would also be less likely to use transit. As with comparable white and African American travelers, the likelihood of walking decreases dramatically with neighborhood density. The likelihood of using transit, while not particularly high, is less sensitive to density.

Carless students are far more likely to walk than any other groups except poor African Americans, regardless of where they live. The probabilities that a car-less student living in the Nob Hill and Noe Valley neighborhoods will walk exceed .75 and .60, respectively. Car-less students living in Oakland's Rockridge neighborhood and Downtown San Jose are almost as likely to walk as to use all other modes. Only students living in low-density South San Jose are reluctant to walk. Surprisingly, except for residents of Nob Hill, the likelihood that car-less students will use transit is generally less than 10%.

Poor mothers who share a car are likely to walk only when they live in high-density, mixed use neighborhoods. Outside such neighborhoods they are far less likely to walk. Regardless of what neighborhood they live in, low-income moms are unlikely to use transit, even (as in the Nob Hill neighborhood) when the quality of service is fairly high.

In summary, among non-work trips, neighborhood and built-form characteristics account for substantial variations in pedestrian activity, but far less variation in transit use. Depending on their gender and access to a private car, residents of fine-grained, high-density neighborhoods may walk to as many as three-quarters of their non-work destinations. Similar residents of more homogeneous and lower-density neighborhoods will tend to walk far, far less. Transit use for non-work purposes is much lower varying from a high of 15% among car-less residents of high-density neighborhoods, to less than 1% among residents of low-density suburban neighborhoods.

CONCLUSION AND FUTURE DIRECTIONS

This research provides some evidence that built-form characteristics and mode choice are correlated while controlling for a variety of socio-demographic factors that influence transport choice. These relationships are significant and in the directions suggested by theory. However, they are generally moderate in magnitude with the exception of trips for access to transit.

These findings are subject to several qualifications. First, by focusing on the behavior of individual travelers, this approach ignores related and joint travel decisions by multiple household members. Multilevel (or “mixed”) modeling would allow for the parameterization of these interrelationships. Second, although efforts were made to pick the best set of explanatory variables while reducing multi-collinearity, in the real world, effects are not so easily isolated: socio-demographic characteristics are correlated with each other, built-form characteristics are correlated with each other, and socio-demographic characteristics are correlated with built-form characteristics. Finally, while this research shows a relationship between built-form and mode choice, it does not establish that this relationship is causal. It is quite likely that people who prefer to walk or ride the bus choose to live precisely in neighborhoods that make that easier and more enjoyable to do. In many cases, altering the built-form of auto-oriented neighborhoods to make them more pedestrian-oriented without also changing their socio-demographic characteristics would have only a minimal effect on travel behavior. Addressing this issue of *simultaneity* requires collecting much more extensive data and developing more complex behavioral models.

In addition, a number of improvements could be made to better represent the built environment. Many relationships are non-linear and/or exhibit threshold behavior; modeling such relationships using simple interval and nominal measurements may miss more subtle effects. Simple variables, such as the amount of commercial land within a certain distance, ignore deeper questions about the attractiveness of specific commercial uses; travelers willing to walk a quarter-mile to a neighborhood coffee shop may be unwilling to walk even 100 feet to a neighborhood gas station. Although each of these issues may be small individually, cumulatively, they limit our ability to reliably model the influences of built-form on travel behavior.

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[1] The relative utilities of cyclists and transit users are not shown but are expected to be intermediate between the two lines.

[2] Hypothetical simulations use simple rules to project overall transportation changes and are important to consider because they are by far the most common way of predicting the results of real-world planning decisions. However, because they lack any type of empirical content, they will not be reviewed here (see Handy 1996 for an overview).

[3] The use of one-kilometer rings centered on each residence is the closest approach in the literature to the localized measurement used in this paper.

[4] The Los Angeles region, in which much of Crane's and Boarnet's (2001) and Boarnet's and Sarmiento's (1996) work is set, is far more homogeneous than the San Francisco Bay Area with respect to density and neighborhood forms. Likewise, travelers in the Bay Area can avail themselves of a greater variety of travel modes.

[5] Wth the exception of people who have paid a premium to live in "walkable" neighborhoods, such as North Beach in San Francisco and Rockridge in Oakland. In these places, the weekend walk to the neighborhood café is a part of the lifestyle.

[6] Prior research suggests that most walking trips are a quarter-mile or less in length.

[7] In an effort to move beyond these ad hoc rules of thumb, the relevant neighborhood radius could be based on the observed mean trip distance for each mode. Unfortunately inconsistencies in the BATS96 dataset made this simple calculation impossible.

[8] This type of diversity index is sensitive to the coarseness of division between land use classes. It seems unlikely that adding transportation land use (such as a freeway) to a neighborhood will increase the visual diversity as much as adding commercial land use to a fully residential neighborhood so transportation was collapsed into industrial.

[9] Note this raises a problem of slight over-estimation.

[10] Note that lower density TAZs are generally larger than high density TAZs

[11] Nob Hill highlights the difficulties inherent in using parcel size as a proxy for visual interest. Nob Hill's visual interest is based on the presence of interesting and detailed facades, not small street frontages.