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Public Transit In New York: Keep Up with the Trend – A Case Study of Mode Choices in the New York Metropolitan Region

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16. Abstract

We investigate the role of the built environment in mode choice decisions for home-based work tours in the New York Metropolitan Region. The analysis is conducted using a multinomial logit model. There are two main results of this study. First, the built environment influences people's mode choice decisions, even after controlling cost variables. Population and employment densities have explanatory power, so do the variables measuring the access distance between the nearest mass transportation facility and a stop in the tour. Second, tour characteristics do affect mode choices. Mode choice decisions shall be analyzed with tours as the analysis unit.

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Introduction

Commuting - the every day trip from home to work – remains at the core of urban transportation problems (Horner 2004). In the 21st century, more people are commuting to work and their commute times are longer (Pisarski 2002; Sultana 2002; Bram and McKay 2005). While congestion can occur at any hour and on any day of the week, it is still typically the worst at peak hours when people commute to and from work (Redmond and Mokhtarian 2001). Mode choice is an important attribute of urban commuting. According to the 2000 census, 76% of the American workers drive alone to work by automobile (Pisarski 2002). The overwhelming use of automobiles in this country contributes to growing urban problems including traffic congestion, air pollution, and energy inefficiency. Over the years, various strategies have been proposed to persuade auto drivers away from their cars and these strategies include Transportation Demand Management (TDM) strategies, Transportation Supply Management (TSM) strategies, and most recently land use management strategies. The recent interest in land use policies has again stimulated studies in examining how the built environment affects people's mode choice decisions (Cervero 1996; Kitamura et al. 1997; Ewing and Cervero 2001).

The built environment refers to any attribute characterizing land use patterns and/or transportation infrastructure (TRB 2005). Population and employment densities are the most frequently tested land use variables in studies of mode choices. These two variables are often found to be negatively correlated with the probability of using automobiles (Cervero 1994; Frank and Pivo 1994; Zhang 2004). Does this finding suggest that high levels of population and employment densities would lead to an increase in the use of alternative modes of transportation? High density in general is associated with lower automobile ownership and better transit service, which would suggest a shorter travel time for transit as compared to automobiles (Kitamura et al.

1997). Crane and Crepeau (1998) argued that the impact of the built environment on travel behavior is mediated through cost variables. If cost variables were excluded, the observed significant built environment impact may be spurious. Handy (1996) asked “is it density or the variables that go along with the density [that affect the mode choice decisions]?” The first objective of this study is to examine the impact of population and employment densities on mode choice decisions, while controlling for cost variables.

Variables characterizing the transportation infrastructure of the built environment measure how the quality and/or quantity of the transportation facilities in an area affect one’s mode choice decision. Obviously one’s decision to use a transportation mode (such as subway) depends on the availability and accessibility of the transportation facilities. From this perspective, accessibility to transportation facilities should be part of the mode choice analysis. The question is how the role of transportation infrastructure differs from that of the cost variables? If we control for cost variables such as total travel time, which includes the access time to and from transportation facilities, does the accessibility to transportation facilities still play a role? The second objective of this study is to answer this question.

In addition to contributing to discussions on how the built environment influences mode choice decisions, this study is different from many previous mode choice analyses by focusing on tours. It is well recognized in the literature that people chain multiple trips together into tours (Hanson 2004). As journey to work often involves more than one destination nowadays, people frequently make decisions about how and where to combine activities as part of the journey to work, and via what mode of transportation. However, empirical studies on mode choices of a single trip still far exceed those on a tour (Miller et al. 2006). In this study, we analyze how tour level characteristics affect mode choice decisions for home-based work tours.

The study is set in the New York Metropolitan Region. This is an ideal place to study mode choice decisions because of the diversity in population demographics, the range of transportation alternatives offered, and the land use mixes and densities. The population density at the county level ranges from 45,499 ppsm (persons per square mile) in Manhattan to only 268 in Sussex County, New Jersey. The region also offers the most comprehensive mass transportation network in the United States. The subway and bus systems within New York City carry a monthly ridership of about 110 million and 70 million respectively (MTA 2006). Commuter rails from the suburbs in New York State carry a monthly ridership of roughly 13 million[1], in addition to the millions carried from New Jersey and Connecticut suburbs on heavy rail systems.

The remainder of the paper is organized as follows. In Section 2, we provide a review on the mode choice literature. Given the large volume of literature pertaining to mode choice, the focus is on recent developments. In Section 3, an empirical dataset used in this study is described. We apply the Multinomial Logit Model to the sample and the model is described in Section 4. We present our model results in Section 5. Last, discussions follow in Section 6.

Prior Research

The insight that where one lives might affect his or her travel behavior is not new. The familiar four-step travel demand forecasting model, which was developed in the 1950s, used population density and retail density as the built environment variables to forecast trip generation and trip distribution from and to each unit of analysis, typically called a Transportation Analysis Zone

[1] The 13 million count only includes Long Island Rail Road and Metro North, both of which serve trips between nearby suburbs (e.g., Westchester County, Suffolk County, etc.) and New York City. The number does not count the ridership on Amtrak, which typically serves trips with a longer distance.

(TAZ). Pushkarev and Zuppan (1977) plotted the mode share for mass transit as a function of population and retail densities at trip origins and trip destinations; they found that both population and retail densities are important factors affecting the mode share of mass transit. Both the "new urbanist" movement in the 1980s (Kelbaugh 1989; Katz 1994) and today's smart growth policies use the built environment and modifications of this environment to influence travel behavior.

One important attribute of the built environment is its land use pattern (Ewing and Cervero 2001; TRB 2005). As the most popular land use variables, population and job densities are found to be positively associated with the levels of usage for transit and non-motorized modes (Cervero 1994; Ewing and Cervero 2001; Frank and Pivo 1994; Zhang 2004)[2]. For example, using the 1996 Bay Area household travel survey, Reilly and Landis (2002) found that higher population density is associated with higher probability of walking or taking transit. On average, an increase in the average density of four persons per acre within one mile of an individual's residence is associated with a 7% increase in the probability of walking or taking transit. The question is whether it is the density or other covariates (e.g., travel cost, travel time) going along with the density that affect travel behavior (Handy 1996). Areas that are dense in population often have clustered opportunities for work or non-work related activities. Clustered population and/or activities are necessary conditions for a competitive transit service (Giuliano 2004). From this perspective, population and employment densities may be merely proxies for variables that represent the quality of the transit service: headways, reliability and total travel time. In this study, we test the role of population and employment densities on mode choice decisions, while controlling for cost variables. Two scenarios may arise. Insignificance may be

[2] A more thorough review on this issue can be found in several review papers, such as Handy (1996) and Ewing and Cervero (2001).

observed if the densities serve as merely proxies for cost variables. Or, significance may be found if they have their own effects.

Another important attribute of the built environment relates to the access to mass transit and the network that transit serves. The inclusion of such access to service variables as part of the transportation networks category of the built environment is not common. For example, among the 10 papers reviewed by Ewing and Cervero (2001) for transportation networks category, none had such a variable. The included variables under this category often describe the presence and the layout of the local street networks (Kitamura et al. 1997; Boarnet and Sarmiento 1998). Some studies examined the role of the quantity of the bus or rail stops within a certain radius of residence (Titherideg and Hall 2006; Eash 1999). In an alternative argument, variables representing the access to transportation facilities can be viewed as part of the total travel time by mode. In recent mode choice studies (whose focus is not necessarily to examine the impact of the built environment), this practice is also rare. Instead, total travel time by mode is typically included as an independent variable predicting mode choice decisions, while leaving out the variables measuring the access time or distance to transportation facilities (Vovsha 1997; da Penha Sanches and de Arruda 2002; Kim and Ulfarsson 2004; Patterson et al. 2005).

Kitamura et al. (1997)'s study included variables representing access to transportation facilities. However, total travel time by mode was not included. In their study examining the propensity to use a transit mode in five neighborhoods in the San Francisco Bay Area, they found that distance to the nearest bus stop was a statistically significant predictor of the fraction of car trips and distance to the nearest rail stop had a significant negative impact on the total number of transit trips. In this study, we test the role of access distances to mass transit facilities on mode choice decisions while controlling for cost variables. Similar to population and employment densities, access distance variables may be significant if they play their own roles or insignificant if they are merely proxies for cost variables.

While it is widely recognized that people chain their trips and today's trips have become far more complicated than decades ago (Levinson and Kumar 1995), mode choice studies that analyze single trips still far exceed those analyzing tours (Miller et al. 2006). Hanson and Schwab (1986) found that unless the first trip in a tour is a trip to work, the mode choice of a tour is determined by all trips in the tour. The complexity of a tour is also found to have a negative influence on the choice of using mass transit (Henscher and Reyes 2000; Toint and Cirillo 2001). In their work examining the space and time determinants of mass transit use in trip chains in Belgium, Vande Walle and Steenberghen (2006) found that the inability to use mass transit for a single trip in a tour prevented the person from using mass transit entirely. In this study, we test three tour complexity variables: number of stops (including home and work locations) in a tour, New York City (NYC) stop (it is equal to 1 if one of the stops[3] is in NYC), and total number of NYC stops. We expect that the number of stops in a tour is positively related to the probability of choosing the auto only mode. As New York City is associated with long travel time and high parking cost, we expect that the probability of using the auto-only mode drops as the values of last two variables increase.

Many studies that have examined the impact of the built environment on mode choice behavior limited built environment characteristics to residential locations, or trip origins only (Zhang 2004). Because a trip is a movement in space, it is likely that all stops in a tour matter. Shiftan and Barlach (2002) found that characteristics at the work site have significant explanatory power in mode choice decisions. Frank and Pivo (1994) analyzed the choices between drive alone, transit, and walking using the Puget Sound dataset in the Seattle area. They

[3] Includes both home and work.

showed that job density matters more at the destination and population density matters more at the origin in influencing mode choice decisions. Ewing and Cervero (2001) commented that "employment densities at destinations are as important as and are possibly more important than population densities at origins" (p. 92). Similar results were confirmed by Chatman (2003). Using the 2001 Nationwide Personal Transportation Survey, he found that employment density at the work place is more closely related to automobile commuting than residential density. Zhang (2004) found that higher population density at origin encourages the use of walking, biking, and mass transit for work trips but not for nonwork trips, while higher population density at destination mattered for both work and nonwork trips. Higher job density at the origin is insignificant for both work and nonwork trips while higher job density at the destination promotes the use of biking, walking, and mass transit for work trips but not for nonwork trips. In this study, we apply several variables in testing the hypothesis that "all stops in a tour can matter", including the minimum and maximum of single-trip distances in the tour, the maximum population and employment densities of all stops in the tour, and the maximum of access distances between the nearest mass transit facility and all stops in the tour. The inclusion of the maximum density suggests that any stop in a tour can play a role; a single stop in a high-density area (like NYC) might prevent one from using automobile entirely, even though all other stops in the tour can be conveniently reached by automobile. This applies to access distance similarly. It tests our assumption that accessibility from any stop in a tour may matter; a single maximum access distance in a tour can prevent one from using mass transportation entirely, even though all other stops are within reachable distance from mass transportation facilities.

The influence of tour complexity on mode choice decisions raises a question that relates to the endogeneity of the two. The question is whether tour complexity affects mode choice, or vice versa, or are both simultaneously determined. Bhat (1997) develops a joint model framework that simultaneously determines the work travel mode and the number of non-work commute stops. In a 2000 paper, the joint model was further improved to accommodate the entire travel pattern after work, including the mode choice for the evening commute, the number of evening commute stops, and the number of stops after arriving home from work (Bhat and Singh 2000). In a more recent study, Bhat and Sardesai (2006) considered the effects of commute and midday stop-making as well as travel time reliability on the commute mode choice. Ye et al. (2006) compared three possible relationships between trip chaining pattern and mode choice: the trip chaining pattern is determined first and then influences mode choice; mode choice is determined first and then affects trip chaining pattern; and both are simultaneously determined. Using the 2000 Swiss Microcensus Travel Survey, They found support for the first structure - that the determination of trip chaining pattern precedes mode choice for both work and non-work tours. In this study, we assume that the number of stops in a tour is determined prior to the mode choice.

Empirical Dataset Description

Study Area

The New York Metropolitan Region comprises 28 counties in the tri-state area: New York, New Jersey and Connecticut. Figure 1 shows the study area. As of 2000, the total population in the tri-state area was about 21 million. Eight million were living in New York City (NYC), which includes Manhattan, Brooklyn, Bronx, Staten Island, and Queens. About 6.6 million people were in the New Jersey subregion, which includes 14 counties in the northern and eastern New Jersey. These two subregions combined account for almost 70% of the region’s total population.

New York City has the highest employment in the entire region, 3.7 million workers. Manhattan remains the largest employment attraction point in the region; 2 million enter Manhattan south of 60th street every work day (Paaswell and Zupan 1999; Bram and McKay 2005). This is followed by 3.2 million in the New Jersey subregion. In total, the employment of these two regions combined accounts for about 70% of the region's total.

[Figure 1 about here]

As noted, the concentration of 2 million daily work trips in the core of Manhattan is sustained by high speed rail in the city and rail/commuter bus between suburbs and NYC. Eighty percent of the work trips ending in the core are by mass transit; outside the core the transit use drops to one that is more consistent with suburban regions, approximately 25% (Paaswell and Zupan 1999).

Data Source

In 1997/1998, the New York Metropolitan Transportation Council (NYMTC) and the North Jersey Transportation Planning Authority (NJTPA), the Metropolitan Planning Organizations (MPOs) for New York City and Northern New Jersey metropolitan areas respectively, sponsored the Household Interview Survey (HIS).

A total of 14,441 households in 28 counties in New Jersey, New York, and Connecticut were recruited to complete travel diaries over a 24-hour period. The dataset is comprised of data on 27,369 people in 11,264 households and 118,134 trips made by the people. The data was checked against the 1990 Census and the 1995 National Personal Travel Survey for comparability for variables that existed in the relevant datasets. The dataset was found to be comparable with both datasets for most variables.

Study Sample

The sample for this study comprises all commuters who made a home-based work tour on the survey day. We used two criteria to select the sample: 1) the starting and ending points are home; and 2) there is at least one work activity between the starting and ending points. A total of 4,762 tours were selected (Figure 1).

Table 1 shows the frequency distribution of the number of stops that people visit in a home-based work tour. Of all 4,762 home-based work tours, simple 3-stop tours (home-work-home) make up about half. Nineteen percent (19%) of all tours are made with one extra stop in addition to work and 14% of the tours include two extra stops. These three groups make up over 80% of all tours.

[Table 1 about here]

Table 2 shows mode shares of the selected home-based work tours in the New York Metropolitan Region. The non-motorized mode includes walking, wheelchair, skates, and bicycle. The mode for “rail” or “commuter bus” means that people used commuter rail or commuter bus at least once in the tour. The mode for “bus” or “subway” means that people used local bus or subway at least once in the tour and no commuter rail or commuter bus was used in the tour. Therefore, if a tour involves using commuter rail, subway, and walking, it is classified as a tour using the rail/commuter bus mode. In another case, if a tour only involves subway and walking, it is classified as a tour using the bus/subway mode. The “auto only” mode accounts for about 80% of all tours. This is not surprising because about 70% of the sample in the 1997/1998 survey lived outside of New York City, where the dominant mode of transportation is the automobile.

[Table 2 about here]

Table 3 shows the percentage of the sample living or working in NYC by mode. People using bus/subway are most likely to live and work in New York City, followed by those using the non-motorized mode. The dense clustering of population and activities in New York City discourages the use of automobiles. Consequently, those using auto only for all their trips are most likely to live and work outside of New York City. Those who use rail or commuter bus are likely to live in the suburbs and use rail/commuter bus for their commute to New York City.

[Table 3 about here]

Distance matters in mode choice decisions. Table 4 shows the average trip distances of all single trips in a tour by mode. Understandably, the non-motorized mode is the most limited in distance and its average trip distance is the lowest. The next group includes bus, auto, and subway. Trips by rail or commuter bus are the longest.

[Table 4 about here]

Table 5 shows descriptive socio-economic characteristics of the sample. Females use the non-motorized mode more and males use more auto and rail/commuter bus more; this is consistent with the current literature, which found that women are more willing to switch to nonautomobile modes (Matthies et al., 2002). Not surprisingly, people who use the non-motorized mode and take bus/subway are less likely to have driver licenses and own vehicles than those who use auto or rail/commuter bus. Those who use the non-motorized mode and bus/subway are more likely to have an income level of $50,000 or lower than those using auto only or rail/commuter bus. The average age of the four groups is similar, with the exception that the bus/subway riders are slightly younger. The average household size is comparable across all four groups.

[Table 5 about here]

Tour complexity is expected to affect mode choice decisions. The inclusion of NYC related variables reflects the notion that being in or visiting NYC increases tour complexity to some extent, because trips can not be easily made by automobiles due to the high cost of driving and parking in NYC. The average number of NYC stops (including the home and work stops) in a home-based work tour is 2.24, 0.29, 1.38, and 3.08 for modes of non-motorized, auto only, rail/commuter bus, and bus/subway.

Built Environment Characteristics

In this study, we are primarily interested in two sets of variables to represent the built environment: population and employment densities, representing characteristics of land use patterns, and distance to bus/subway or rail/commuter bus stops, representing access to mass transportation facilities. Population and employment densities at the census tract level are obtained from the Census Bureau (2000) and Census Transportation Planning Package (2000). We used ArcGIS to calculate the distance between a stop in a tour (e.g., home, work, or other locations) and the nearest bus/subway or rail/commuter bus stop.

Statistics on three set of population and employment densities are provided in Table 6: average population and employment densities at home, average population and employment densities at work, and average maximum population and employment densities associated with a stop in a tour. People who use auto only have the lowest level of population and employment densities at all locations. The population and employment densities for those using bus/subway are comparable to those using the non-motorized mode, with the exception that the employment density at work for those using bus/subway is substantially higher. We also note that for people using rail/commuter bus, the population and employment densities at home are similar to those using auto, the densities at work are comparable to those using the non-motorized mode or bus/subway. In fact, the employment density at work for this group of people is the highest among the four groups, suggesting that these people tend to work in the core of NYC, where employment density is the highest.

[Table 6 about here]

Statistics on six access related variables are provided in Table 7: average distance between the nearest rail/commuter bus stop and home, average distance between the nearest rail/commuter bus stop and work, average maximum distance between the nearest rail/commuter bus stop and a stop in the tour, average distance between the nearest bus/subway stop and home, average distance between the nearest bus/subway stop and work, average maximum distance between the nearest bus/subway stop and a stop in the tour. People taking auto face the longest distance to transit opportunities. Those taking bus and subway face the shortest distance to mass transportation facilities from all stops in a tour. Those taking rail or commuter bus have a shorter access distance from work to bus/subway than from home.

[Table 7 about here]

Research Methodology

Multinomial Logit Model

The variable of interest in this study is a person's mode choice in a choice set that could at most include four alternatives: non-motorized mode, auto only, rail/commuter bus, or bus/subway. Such a variable is of a qualitative nature; a numerical value can not be meaningfully attached. The qualitative nature of the variable dictates the use of a discrete choice model.

A discrete choice model can be derived under the random utility framework. We assume that the probability of selecting alternative *i* over alternative *j* is equal to the probability that the amount of satisfaction (or utility) obtained by choosing alternative i is greater than that by choosing alternative j (Hensher and Johnson 1981). Mathematically, the choice process can be expressed as:

$$\Pr(i) = \Pr[U_i \geq U_j], \forall\ i, j \in C, \tag{1}$$

where U_i and U_j refer to the total utility or satisfaction obtained by choosing alternatives i and j respectively. Manipulation of this probabilistic equation with various distributional assumptions leads to a range of discrete choice models. For example, if we assume an extreme value distribution, the above equation will lead to:

$$\Pr(i) = \frac{e^{V_i}}{\sum_j e^{V_j}}, \forall i, j \in C, \tag{2}$$

where V_i and V_j refer to the systematic (non-random) utilities of alternatives i and j. Typically, V_i and V_j are expressed as the weighted linear functions of generic[4] variables such as travel time, and alternative-specific[4] variables such as socio-economic variables at the household and individual levels and built environment related variables. Equation (2) is the formulation of a multinomial logit model expressing the relationship between the probability of selecting alternative i and the attributes of alternatives in the choice set, denoted as C. Compared to models based on other distributional assumptions (e.g., probit model is derived from the normal distributional assumption), the biggest advantage of the logit model is that it has a closed form solution. Thus, the logit model provides a simple way to calculate and interpret the probability of choosing a mode. Interested readers may refer to Ben-Akiva and Lerman (1985) for more

[4] We will discuss generic and alternative-specific variables in the latter part of this section.

explanations for multinomial logit models.

In this study, we use the multinomial logit model for home-based work tours in the New York Metropolitan Region. Each unit of observation represents a tour, comprising two or more trip legs. The dependent variable in the model is the mode choice for a tour, with four possible modes of transportation: non-motorized, auto only, rail/commuter bus, and bus/subway. This suggests that there are four systematic utility functions (V_j, j = 1, 2, 3, 4) in the model, each associated with a particular mode.

The independent variables in this study can be grouped into two types. The first type is generic, meaning that the variable has the same marginal utility or disutility regardless of the mode. An example of this type is travel time. A generic variable can be estimated with a single variable showing up in all utility functions. The estimated coefficient on this single variable indicates the utility or disutility associated with a one-unit increase in the variable. Take an example of travel time in minutes. An estimate of -0.10 suggests a reduction of 0.10 utility for every 1 minute increase in travel time for all modes. The second type is alternative-specific, which represents the differences in preferences for different modes. Alternative-specific variables included in this study are those describing the tour complexity, the built environment, and socioeconomic characteristics of the decision makers in the study sample. An alternative-specific variable can not be estimated with a single variable showing up in all utility functions. At maximum, an alternative-specific variable can be included in (J-1) utility functions, where J is the total number of transportation modes considered in the analysis. This leaves at least one utility function in which the value for that variable is automatically set to be zero. In variable interpretation, the estimate is related to the utility function of the corresponding alternative. Take the “male” variable as an example. It can be entered into at most three of the four utility functions. Let us suppose that this "male" variable is entered into the utility function only for the auto mode, suggesting that males have a higher or a lower propensity to use auto as compared to the other three non-automobile modes. It also implies that that the values of the "male" variable for the other three modes (non-motorized, rail/commuter bus, and bus/subway) are automatically set to be zero. A positive coefficient on this "male" variable in the auto utility function would indicate a higher probability of choosing auto (as compared to choosing other three modes) for males.

Results

A multinomial logit model described above is estimated for the selected sample using the Nlogit software. The estimation results are shown in Table 8[5]. The goodness of fit of the model is good. With respect to the model with no coefficients, the estimated model represents a 78% improvement; with respect to the model with constants only, the estimated model represents a 57% improvement. For disaggregate datasets, these goodness of fit indices are beyond being just satisfying (Greene 2003).

Census tract-to-census tract travel time represents travel cost by mode. As expected, travel time has a negative coefficient, suggesting that the longer the travel time, the lower the probability of choosing a mode. In addition to travel time, we also use trip distances in the model as cost variables. Instead of examining the distance of the entire tour, we test the impact of the minimum and the maximum distances of all trip legs in a tour on the mode choice selection. As explained earlier, the maximum and the minimum trip distances act as tour-level variables in the model. In this sense, the maximum and the minimum trip distances included in

[5] Not all variables discussed in the "Empirical Dataset Description" Section are included in the model due to the requirement of the logit model (discussed in the "Research Methodology" Section) or its correlation with other variables in the model.

the model not only capture part of the cost effect, but also part of the tour characteristics. The results suggest that the minimum trip distance in a tour plays an important role. The longer the minimum trip distance in a tour is, the less likely it is for a person to use the non-motorized mode as compared to other modes[6]. The impact of this variable on auto only and rail/commuter bus modes is slightly larger than that on the bus or subway mode, suggesting that an increase in one unit of the minimum trip distance in a tour will increase the probability of choosing the auto or commuter rail/commuter bus mode more than that of the bus/subway mode.

We tested the impact of tour complexity on mode choices for home-based work tours. The number of stops is not significant for the non-motorized, the commuter rail/commuter bus mode, but is significantly positive for the auto only mode. The significance on the auto only mode is within our expectation and consistent with existing studies (Henscher and Reyes, 2000; Toint and Cirillo, 2001). If the home-based work tour includes one or more New York City stops (which is associated with high population and employment densities), the choice of using auto drops significantly. This is reflected in the coefficients estimated for a New York City related variable: the dummy variable "NYC stop". If one of the stops is in NYC, it decreases the probability of taking auto. More simply put, the costs of driving in a very dense network are too high; compromises are made on the number of added trips in a chain[7].

The model incorporates two types of variables for measuring population and employment densities. One is population and employment density at home and the other is the maximum population and employment densities associated with a stop in the tour. This maximum

[6] The significant and positive coefficients for auto only, rail/commuter bus, and bus/subway modes suggest that long minimum trip distance will lead to a higher probability of choosing these three modes. Equivalently, this implies that longer minimum trip distance will result in a lower probability of choosing the non-motorized mode.

[7] One factor not noted in this paper is the attractiveness of employment in the core of Manhattan. The median income of workers in the core is 50% higher than all workers in the region. The rewards of work often overcome the costs of getting there.

population or employment density could be at home, at work, or at any other intermediate stop in the tour. Not all these variables are significant. Population density at home is significant at the 5% level only for the rail/commuter bus mode. Its negative coefficient suggests that higher level of population density at home will result in a lower probability of choosing rail/commuter bus. This reflects the fact that many people taking rail/commuter bus to work are those who live in the suburbs and work in the city. Employment density at home is significant at the 5% level only for the non-motorized mode. Its positive value suggests that higher employment density at home will encourage the use of the non-motorized mode. This finding is consistent with our observation that a substantial share of non-motorized users lives in New York City (Table 3), where the employment density is high. The maximum population density is significant for the auto only mode and the rail/commuter bus mode at the 5% level. In both cases, the coefficients are negative, suggesting that in comparison to the non-motorized and bus/subway modes, an increase in the maximum population density in a tour would decrease the use of auto only and rail or commuter bus. The magnitude of the coefficient for the auto only mode is smaller than that of rail/commuter bus mode, suggesting the effect on the auto only mode is less than that on the rail/commuter bus mode. The maximum employment density is significant and positive for the non-motorized mode and is significant and negative for the auto only mode, suggesting that higher level of the maximum employment density in a tour encourages the use of the non-motorized mode, but discourages the use of the auto only mode. This finding is reasonable.

In general, the findings on population and employment densities agree with the literature that relates population and employment densities positively with the probability of using the non-motorized mode or transit (Cervero 1994; Ewing and Cervero 2001). They also confirm our expectation that all stops in a tour matter; this is shown by a set of minimum and maximum related variables. The word “stops” here goes beyond home and work places, as others have shown (Zhang 2004; Shiftan and Barlach 2002). Furthermore, our results suggest that population and employment densities have varying impacts at different stops (densities at home vs. the maximum value associated with a stop in a tour) for different modes, as shown by the differences in the significance and magnitude of the same variables used for different modes and at different stops in the tour.

Four access variables were examined in the model. They are: distance between the nearest rail/commuter bus stop and home, maximum of the distances between the nearest rail/commuter bus stop and all stops in a tour, distance between the nearest bus/subway stop and home, and maximum of the distances between the nearest bus/subway stop and all stops in a tour. Among the four, the two access variables associated with rail or commuter bus are significant and negative at the 5% level, suggesting a negative relationship between access distance and the probability of using rail/commuter bus. This is consistent with Kitamura et al. (1997)’s study which found a negative relationship between the distance to the nearest rail stop and the total number of transit trips. In theory, a higher propensity to use transit is associated with more transit trips. The significance on the maximum distance variable again confirms that all stops matter.

In terms of the impact of socio-economic characteristics, four variables are significant at the 5% level. All are within expectations. Compared with females, males are more inclined to take the auto only mode. The more vehicles are available to a person, the more likely he/she will take the auto only mode. More children under 12 years old increase the probability of choosing the auto only mode. This is probably because auto provides a convenient way to organize trips when there are small children around. Holding a driver license decreases the likelihood of using the non-motorized mode.

[Table 8 about here]

Discussions

There are two main results of this study. First, the built environment has an impact on people's mode choice decisions. Even after controlling cost variables such as travel time and trip distances, population and employment densities still have explanatory power on mode choices. This is also true for variables measuring the access distance between the nearest mass transportation facility and a stop in the tour. Second, tour characteristics do affect mode choices. Tour characteristics not only include the three variables describing the tour complexity, but also those related to the minimum and maximum distances for a trip leg in a tour, the maximum population and employment densities, and the maximums of access distances between the nearest rail/commuter bus or bus/subway stop and all stops in a tour.

The current study confirms the importance of modeling mode choice decisions as tours instead of single trips. Furthermore, the current study adds to the literature by going beyond home and work locations. By utilizing the minimums and the maximums in a tour for several variables (e.g., population and employment densities, trip distances, and access distances to mass transportation facilities), our study demonstrates that any stop (home, work, or any other intermediate stops) in a tour can have a significant effect on mode choice decisions.

This study contributes to the literature with its evaluation of the role of population and employment densities in mode choice decisions while controlling for cost variables such as travel time and trip distances, as Crane and Crepeau (1998) suggested. The results suggest that although it is likely that the built environment variables exert their influence through cost variables[8], these cost variables as an intermediate force do not entirely capture the built environment effect on mode choices. In other words, the built environment variables are likely to have their own and direct effects on mode choice decisions. Our answer to Handy (1996)'s question "is it density or the variables that go along with density [that affect mode choice decisions]?" is as follows. Clearly, the variables that go along density are important factors in mode choice decisions. In addition, the current study suggests that densities themselves are also likely to play a role. One possible effect may be psychological. People who are not familiar with driving in a dense area might perceive auto driving as unpleasant and stressful and thus avoid commuting by car. Given that our study does not include all possible built environment variables, this conclusion is yet to be verified by other investigators.

Similarly, the significance we found in variables measuring the distances between the nearest mass transportation facility and a stop in the tour points out the importance of including these access distance related variables as part of the built environment characteristics, in addition to population and employment densities.

The study uses a cross-sectional dataset from the New York Metropolitan Region. It lays out associations between mode choice decisions and the built environment, while controlling for cost variables. What is not answered in this study is the causality between the built environment and mode choices. Because people self-select into different neighborhoods (NYC vs. suburbs and short access distance vs. long access distance), we can not conclude that it is the built environment that causes the differences in mode choices for home-based work tours. A similar

[8] Density can be related to travel time by mode. Mass transit is often more competitive in a dense area, as compared to auto driving. This competitiveness may contribute to the observation of a higher market share of mass transit in a dense area. Density can also be related to trip distances. Because of the clustering of activities in a dense area, trips made by people living in a dense area may be shorter than those made by people living in an area with scattered developments. Automobiles are not competitive in short-distanced trips. Alternative modes other than auto, on the other hand, are. This may also contribute to the higher level of market share of alternative modes observed in a dense area.

but probably a less significant self-selection bias applies to work sites as well. Because people also choose to accept or reject a job offer, we are in no position to conclude that work site related characteristics can cause differences in mode choices. The best way to answer the causality question is via a panel dataset using a structural equation systems method (Cao et al. 2006). The cross-sectional nature of the current dataset in the New York Metropolitan Region does not allow us to perform such an analysis. However, it is certainly worthy of future pursuit, as datasets become available.

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Table 1 Frequency of Number of Stops[1] in a Home-based Work Tour

Number of Stops	**Number of People**	**Percent**
3	2,489	52%
4	895	19%
5	695	14%
6	318	7%
7	169	3%
8	98	2%
9	48	1%
10	28	1%
11	22	1%
Total	4,762	100%

[1] The number of stops includes the starting and ending home position.

Table 2 Tour Mode Shares

Mode	**N**	**Share**
Non-motorized (walk, wheelchair, skates and bicycle)	127	0.03
Auto only	3838	0.80
Rail/commuter bus	350	0.07
Bus/subway, no rail/commuter bus	447	0.09

Table 3 Shares of People Residing and/or Working in NYC by Mode

	Modes of the Tour			
Variables	***Non-motorized***	***Auto Only***	***Rail/commuter bus***	***Bus/Subway***
Number of observations	127	3,838	350	447
Residing in NYC	56%	12%	18%	80%
Working in NYC	57%	14%	83%	90%

Table 4 Average Distances[1] of All Trips by Mode for the Sample

Mode	**Mean (miles)**	**Std. Dev. (miles)**	**# of Trips**
Non-motorized	1.36	4.31	1553
Auto only	8.24	10.70	14670
Commuter rail	25.64	14.47	347
Local bus	6.07	6.96	363
Commuter Bus	16.21	10.70	265
Subway	10.09	10.94	935

[1] Distance measured in straight line miles.

Table 5 Descriptive Socio-Economic Statistics of the Study Sample

	Modes of the Tour			
Variables	***Non-motorized***	***Auto only***	***Rail/commuter bus***	***Bus/subway***
N	127	3838	350	447
Gender				
Male	46%	54%	63%	52%
Female	54%	46%	37%	48%
License				
Yes	86%	100%	95%	82%
No	14%	0%	5%	18%
Income Levels				
<50,000	42%	29%	19%	39%
>=50,000	58%	71%	81%	61%
Mean Values				
Age	40	42	40	39
Household size	2.7	2.9	2.7	2.8
# of vehicles	1.5	2.3	1.9	1.4

Table 6 Population and Employment Densities of the Sample (persons per square miles)

	Modes of the Tour			
Variables	***Non-motorized***	***Auto Only***	***Rail/commuter bus***	***Bus/ Subway***
Avg. population density at home	55,222	9,932	10,383	60,520
Avg. employment density at home	38,238	3,594	4,726	23,849
Avg. population density at work	42,096	11,453	30,402	39,680
Avg. employment density at work	144,189	21,485	424,226	297,652
Avg. max. population density	62,436	15,444	35,739	74,890
Avg. max. employment density	145,328	22,367	431,649	334,140

Table 7 Transportation Access Characteristics of the Sample (in feet)

	Modes of the Tour			
Variables	***Non-motorized***	***Auto Only***	***Rail/commuter bus***	***Bus/ Subway***
Number of observations	127	3,838	350	447
Avg. distance between home and the nearest bus/subway stop	3,126	16,858	4,810	954
Avg. distance between home and the nearest rail/commuter bus stop	3,798	11,211	5,047	2,553
Avg. distance between work and the nearest bus/subway stop	2,941	11,025	711	348
Avg. distance between work and the nearest rail/commuter bus stop	3,585	7,463	984	1,226
Avg. Max. dist. between a stop and the nearest bus/subway stop	3,396	19,816	5,295	1,101
Avg. Max. dist. between a stop and the nearest rail/commuter bus stop	4,484	13,906	5,527	3,199

Table 8 Model Estimation Results

(*: variables significant at the 5% level)

	Non-motorized	Auto only	Rail/commuter bus	Bus/subway
Variables	Coefficient	Coefficient	Coefficient	Coefficient
Constant		6.5110*	1.3887	-5.4177*
Cost variables				
Travel time	-0.0034*			
Maximum distance for a single trip leg		-0.0222	0.0107	-0.0493
Minimum distance for a single trip leg		0.4111*	0.4219*	0.3882*
Tour complexity variables				
# of stops in a tour	-0.0559	0.14590*	-0.0651	
NYC stop (=1 if one of the stops is in NYC)	-0.9092	-0.7090*		
# of NYC stops	0.0911			

A cell with a blank space means that the variable did not enter into the utility function for the corresponding mode for model estimation. There may be two possible reasons for the blank space. First, in a multinomial logit model, an alternative-specific variable can only be entered into, at maximum, (J-1) number of utility functions, where J is the number of transportation modes considered in the analysis (in this case, J = 4). Second, a variable is not included into the utility equation if it is found to be strongly correlated with other variables already included into the equation and these other variables are more significant. An example of this variable is the maximum employment density for rail/commuter bus, which is found to be strongly correlated with the employment density at home for the same mode.

Table 8 Model Estimation Results (cont'd)
(*: variables significant at the 5% level)

	Non-motorized	Auto only	Rail/commuter bus	Bus/subway
Built environment variables				
Log of Population density at home	-0.3314	-0.1862	-0.3273*	
Log of Employment density at home	0.3768*	0.0269	-0.1249	
Log of Max. population density	-0.0529	-0.2922*	-0.3349*	
Log of Max. employment density	0.3571*	-0.7786*		
Distance to the nearest rail/commuter bus or bus/subway stop from home			-0.1934E-03*	0.4667E-04
Max. of the distances to the nearest rail/commuter bus or bus/subway stop from all stops in a tour			-0.2254E-04*	-0.2318E-04
Highway density in home census tract		-51.0803		

Table 8 Model Estimation Results (cont'd)

(*: variables significant at the 5% level)

	Non-motorized	Auto only	Rail/commuter bus	Bus/subway
Socio-economic variables				
Male		0.4063*		
Number of vehicles per person		1.1313*		
# of kids under 12 years old	-0.1252	0.4302*		
License holder	-1.0137*			
Goodness of Fit Statistics				
Log-likelihood (model)	-966			
Log-likelihood (no coefficient)	-4,364			
Log-likelihood (constants only)	-2,235			
Adjusted ρ with respect to the no-coefficient model	0.78			
Adjusted ρ with respect to the constants-only model	0.57			

Figure Caption

Figure 1 Study area and home locations of the study sample.