Curbing automobile use for sustainable transportation: analysis of mode choice on short home-based trips

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Abstract This paper analyzes transportation mode choice for short home-based trips using a 1999 activity survey from the Puget Sound region of Washington State, U.S.A. Short trips are defined as those within the 95th percentile walking distance in the data, here 1.40 miles (2.25 km). The mean walking distance was 0.4 miles (0.6 km). The mode distribution was automobile (75%), walk (23%), bicycle (1%), and bus (1%). Walk and bicycle are found less likely as the individual's age increases. People are more likely to drive if they can or are accustomed to. People in multi-person families are less likely to walk or use bus, especially families with children. An environment that attracts people's interest and provides activity opportunities encourages people to walk on short trips. Influencing people's choice of transport mode on short trips should be an important part of efforts encouraging the use of non-automobile alternatives.

Keywords Short trip · Travel behavior · Sustainable transportation · Mode choice · Built environment

Introduction

The convenience of the personal automobile with its instant availability, point-to-point travel, and high speed has made it an integral part of daily life for a multitude of people. The automobile's utility has deeply influenced people's lifestyles and subsequently, the physical landscape. In the United States (U.S.), vehicle miles traveled (VMT) per capita have increased from 6,742 in 1980 to 9,941 in 2003, a 47.5% increase (BTS 2005). This

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increase has largely occurred in urbanized areas where low-density suburban development is prevalent.

The U.S. population travels a greater distance per day than the population of any other nation in the world and this translates into U.S. residents making nearly four automobile trips per person per day. For example, western European populations make an average of only two to three automobile trips per day (Schafer 2000). This is reflected in an international comparison between the U.S. and four European countries (France, Germany, Sweden, and the United Kingdom). Total annual automobile VMT per capita in the U.S. was 41.4% greater than the average of the four European countries whereas the number of automobiles per capita in the U.S. was only 8% higher than the average of the four European countries (OHPI 2000). As OHPI (2000) argued, Americans' love affair with automobiles may be a marriage of convenience due to widespread low-density land use development. However, low-density suburban development is not only a U.S. phenomenon. For instance, the average distance traveled to work has increased globally, including European nations with greater population densities than the U.S., despite land-use policies aimed to reduce traffic (Schafer 2000).

In the U.S., personal automobiles are used for 91.2% of all personal travel while public transit (2.1%), walking (0.3%), and biking (0.1%) play minimal roles with respect to personal travel (OHPI 2000). In the U.S., automobile dependency is associated with various personal, household, travel, and environmental factors in addition to the conveniences provided by automobiles. The demographic shift due to an aging population has an effect on mode choice and automobile dependency (Kim and Ulfarsson 2004). Physical disabilities, the need to travel with children, carrying heavy goods, vehicle availability, lifestyle, socio-economic status, expected effort required to use public transit or non-motorized alternatives, and safety are examples of important factors. Previous research has also indicated that land use influences automobile dependency substantially (Cervero 2002; Srinivasan and Ferreira 2002) even though some argue that the effect is often questionable or minimal (Boarnet and Sarmiento 1998; Crane and Crepeau 1998).

Various socio-economic and environmental issues associated with high automobile dependency have encouraged the development of policies to discourage automobile use in numerous countries. However, an often neglected issue of the efforts to reduce traffic is the use of automobiles on short trips. Several European studies argued that it is particularly necessary to target short trips to curb automobile use and associated negative externalities (Black et al. 2001; Hillman 1998; Loukopoulos and Gärling 2005; Mackett 2003; Mackett and Robertson 2000; Nolan and Kunreuther 1995). The convenience and instantaneous nature of personal automobiles make it difficult to reduce automobile use in suburban or exurban areas where activity locations are dispersed and few transportation alternatives exist. However, opportunities for alternatives such as walking and biking are realistic on short distance trips.

Reducing automobile use on short trips can contribute to reducing traffic congestion. Short trips tend to be non-work trips in the U.S. and a significant number occur during the peak hours. Lee et al. (2006) reported that about half of all 6–9 a.m. trips are for non-work and about two-thirds of all 4–7 p.m. trips are for non-work in major U.S. metropolitan areas. It should be clarified that many of these non-work trips are parts of a work-related trip chain, e.g. a stop at the dry cleaners on the way to or from work.

Curbing the use of automobiles for short trips can benefit the environment. It was reported that personal automobiles emit about 10% of global CO_2 emissions and the U.S. contributes about 45% of the world's automotive CO_2 emissions (DeCicco and Fung 2006). Short automobile trips often result in driving with a cold engine and thus these trips

generate a higher level of environmentally hazardous exhaust emissions (Loukopoulos and Gärling 2005).

Short trips provide opportunities for physical exercise for trip makers. Even though walking has sometimes been regarded as a mode of exercise rather than a mode of travel (Handy et al. 2002), walking can play an important role as an alternative mode of transportation, especially for short trips.

Each of these is a compelling reason to focus on short trips when attempting to reduce automobile use. There are European studies on the characteristics of short trips. For instance, a Swedish study (Loukopoulos and Gärling 2005) investigated the mean distance threshold for walking versus driving. The distance was reported as 4.1 km. The study found that females had a higher threshold than men, and habitual automobile users—in terms of driving frequency—had lower distance thresholds. Conversely, walking frequency has a positive relationship with distance thresholds. Perceived exertion required for walking and the individual's age are negatively associated with the distance threshold.

A British study (Mackett and Robertson 2000) based on the UK 1997/1999 National Travel Survey found that 44% of trips were less than 2 miles (3.2 km) in length and 35% of these were by automobile. The automobile was used for 18% of trips of less than 1 mile (1.6 km). Walking accounted for 80% of trips of less than 1 mile and 58% of trips of less than 2 miles. Bicycle and bus are rarely used for short trips and each accounted for 1% of the mode share and accounted for only 2% and 3% respectively for trips of less than 2 miles. School trips, pick-up/drop-off trips to school, shopping, and personal business are more likely to be short trips. The study also reported that trip purpose is the main factor influencing automobile use on a short trip. The study reported that females make more short trips than males. In urban areas, automobiles are used more on short trips because of time constraints and to pick-up/drop-off other people. In rural areas, people use automobiles for social activities and because of the distance to activities. Automobiles tend to be used on short trips to work when they are available. Walking and bus use on short trips occur more in high-density areas and there is more cycling in relatively level areas as opposed to hilly areas.

There are several reasons for driving automobiles on short trips. Mackett (2003) reported that carrying heavy goods is the most common reason followed by picking-up/dropping-off another person, time constraints, long distance, and convenience. The need for an automobile on another later trip is also a main reason. Mackett (2003) also reported that males are more likely to use automobiles on short trips because their trip lengths are often longer than those of females and due to vehicle needs at work. Females said that their main reason to use automobiles on short trips is picking-up/dropping-off family members. Also, the elderly are more prone to using automobiles. In terms of levels of urbanization, rural residents are more likely to use automobiles for carrying heavy goods on short trips while urban residents disproportionately responded that the time budget is the main reason for automobile use on short trips. Walk (31%) and bus (31%) are the most common alternatives to driving automobiles and 78% of the survey participants said they have alternatives to automobiles on short trips.

There are additional factors that influence the mode choice for short trips. These may include socioeconomic status, health condition, vehicle availability, driving frequency and habit, whether the trip is chained to other trips, trip companion, time constraint, topography, weather, availability and quality of alternative modes and perceived exertion of the modes, parking constraints, need of automobile at work, and safety. Loukopoulos and Gärling (2005) argued that it is unlikely that all these factors are taken into account for short trips given what is known about the limits on people's capacity to process

information. However, it may be difficult to exclude those factors when considering people's travel behavior.

While these largely European studies provide important insights into travel behavior, additional investigations are warranted to further develop an understanding of short trips. Existing studies of the factors associated with travel mode choice for short trips are for the most part descriptive in nature. In addition, it is necessary to investigate this issue in the U.S. where driving is most intensive and the associated socioeconomic and environmental issues are tremendous. This study presents a statistical multivariate investigation of the impact of various personal, household, trip, and residential environment characteristics on trip mode choice for short home-based trips using survey data from the U.S. Short non-home-based trips are important as well and warrant a separate study. Non-home-based trips are likely to be different from home-based trips with regard to the influencing factors and complexities arising from different trip chain patterns and mode constraints, necessitating a separate statistical model framework.

Data

The data is drawn from the 1999 Household Activity Survey Data of the Puget Sound Regional Council (PSRC) for the Central Puget Sound region which roughly centers on the Seattle metropolitan area of the State of Washington, U.S.A. This activity survey data includes various personal and household characteristics of the respondents in addition to their 2-day activity records. Neighborhood variables such as population and employment density were obtained from the PSRC 1999 employment records file and 2000 U.S. Census population data.

In this paper, a trip is defined as a unit of home-based (originating at home) travel that involves the use of a single transportation mode for a single purpose, similar to the study conducted by Mackett (2003). We omit the trips of children and focus the study on adults, defined as those 18 year old and older. The data has about 12,900 such trips. The mean distance of walking trips in this data is 0.36 miles (0.58 km) with a 95th percentile of 1.39 miles (2.24 km). We therefore define 1.40 miles (about 2.25 km) as the maximum distance for a short trip in this study. Thus a total of 2,737 weekday trips of less than 1.4 miles were analyzed.

This distance is significantly shorter than the short trip distance investigated in the previously discussed British studies that had a 5 mile (8 km) distance (Mackett and Robertson 2000; Mackett 2003) and in a Swedish study, where the mean distance threshold between walking and driving was 4.1 km (2.6 miles) (Loukopoulos and Gärling 2005). This may indicate that Americans' probable walking distance is significantly lower than that of Europeans, although the data set used in this study is regional, as opposed to national.

This study categorizes the mode choice into four groups: (1) *Walk*, (2) *Automobile*, (3) *Bus*, and (4) *Bike*. Tables 1 and 2 show descriptive statistics for the data used in this study. To further facilitate the analysis, the independent variables are cross-tabulated with the trip mode.

There are more than 2,700 U.S. Census block groups in this region. While each U.S. Census block group may have its own unique characteristics, in order to simplify the analysis, an urban index was constructed using Principal Component Analysis (PCA), a method to develop latent variables. A principal component can be defined as a linear combination of optimally-weighted observed variables. The general form for the formula to compute scores on the component created in principal component analysis is:

Table 1 Descriptive statistics by short trip mode choice

	Walk		Auto		Bus		Bike	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Total	629	22.98	2045	74.72	30	1.10	33	1.21
Personal								
Age								
18–29	114	30.73	237	63.88	11	2.96	9	2.43
30–64	439	22.40	1486	75.82	14	0.71	21	1.07
65+	76	18.72	322	79.31	5	1.23	3	0.74
Mean, SD	43.31	15.28	46.41	15.02	44.23	19.74	40.30	15.28
Gender								
Male	260	24.64	764	72.42	13	1.23	18	1.71
Female	369	21.94	1281	76.16	17	1.01	15	0.89
Ethnicity								
White	573	23.03	1858	74.68	28	1.13	29	1.17
African American/Hispanic	20	18.87	83	78.30	1	0.94	2	1.89
Asian/Pacific Islander	27	25.00	78	72.22	1	0.93	2	1.85
Other	9	25.71	26	74.29	0	0.00	0	0.00
Education level								
College graduate	356	26.14	975	71.59	16	1.17	15	1.10
Some college	147	18.68	620	78.78	8	1.02	12	1.52
High school or less	126	21.43	450	76.53	6	1.02	6	1.02
Driver's license								
Yes	541	20.96	1991	77.14	18	0.70	31	1.20
No	88	56.41	54	34.62	12	7.69	2	1.28
Bus pass								
Yes	60	40.82	71	48.30	11	7.48	5	3.40
No	569	21.97	1974	76.22	19	0.73	28	1.08
Need auto at work								
Yes	0	0.00	22	95.65	1	4.35	0	0.00
No	629	23.18	2023	74.54	29	1.07	33	1.22
Household								
Household income								
Below $25k	140	36.08	237	61.08	9	2.32	2	0.52
$25k–$54k	249	21.65	867	75.39	16	1.39	18	1.57
$55k or above	240	20.02	941	78.48	5	0.42	13	1.08
Length of residence								
Less than 1 year	80	37.56	124	58.22	5	2.35	4	1.88
1–5 years	240	25.92	663	71.60	8	0.86	15	1.62
6–10 years	123	20.71	462	77.78	4	0.67	5	0.84
More than 10 years	186	18.53	796	79.28	13	1.29	9	0.90
Vehicle availability[a]								
1+ per licensed driver	476	20.74	1775	77.34	20	0.87	24	1.05
<1 per licensed driver	153	34.62	270	61.09	10	2.26	9	2.04

Table 1 continued

	Walk		Auto		Bus		Bike	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Household type								
Single person	152	37.44	228	56.16	15	3.69	11	2.71
Married no kids	164	24.85	485	73.48	3	0.45	8	1.21
Married with kids	256	20.51	977	78.29	4	0.32	11	0.88
Other	57	13.48	355	83.92	8	1.89	3	0.71
Trip								
Companion on trip								
Yes	214	20.23	842	79.58	0	0.00	2	0.19
No	415	24.72	1203	71.65	30	1.79	31	1.85
Trip purpose								
Work	112	25.63	306	70.02	14	3.20	5	1.14
School	17	35.42	19	39.58	5	10.42	7	14.58
Shopping	94	15.09	522	83.79	5	0.80	2	0.32
Eat out	43	34.40	80	64.00	1	0.80	1	0.80
Social/recreational	155	32.98	304	64.68	0	0.00	11	2.34
Pick up/drop off	112	18.95	479	81.05	0	0.00	0	0.00
Other	96	21.67	335	75.62	5	1.13	7	1.58
Time: am, pm peak, daytime								
6:30–8:59, 15:30–18:29	220	23.99	674	73.50	12	1.31	11	1.20
9:00–15:29	230	23.23	736	74.34	11	1.11	13	1.31
Distance								
Mean, SD (miles)	0.41	0.31	0.79	0.35	1.06	0.24	0.72	0.34
Activity duration								
Mean, SD (min)	118.41	174.39	94.24	145.63	311.37	213.08	143.45	153.39

[a] Number of vehicles in household minus number of licensed drivers in household

Table 2 Total daily travel and neighborhood characteristics by short trip mode choice

	Walk		Auto		Bus		Bike	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total daily travel								
Trip frequency of the day	5.86	3.11	5.97	3.23	3.20	1.69	5.58	2.99
Travel time of the day (min)	79.98	51.01	69.85	52.98	78.00	44.59	77.09	49.17
Travel distance of the day (miles)	13.66	16.60	18.40	24.76	7.09	12.12	16.33	16.85
Neighborhood								
Urban index	0.88	1.54	0.12	0.97	1.66	1.46	0.32	1.42

$$C_n = b_{n1}(x_1) + b_{n2}(x_2) + \cdots + b_{np}(x_p) \qquad (1)$$

where C_n is each individual subject's score on principal component n, b_{np} is the regression coefficient (or weight) for observed variable p, and x_p is the subject's score on the pth observed variable.

The observed variables used in the PCA to develop the urban index are the year 2000 U.S. Census population density and median year built of buildings, and a retail employment accessibility developed from regional employment data. These variables have been used as major components in classifying areas as urban or rural (Asthana et al. 2002). The median year built of buildings in a neighborhood is used because it proxies for unobserved neighborhood characteristics in the region that have been evolving over time. Previous research, e.g. Berrigan and Troiano (2002), has suggested home age as such a proxy. Notably, the older a neighborhood's median year built, the more rectangular the street network (as opposed to the hierarchical or organic street network in many suburban neighborhoods) in this region. Older areas in the region also have more high density development with commercial areas. Retail employment accessibility is calculated based on Traffic Analysis Zones (TAZ) since traffic data is only available at the TAZ level in the region.

The retail employment accessibility is calculated based on a regional gravity model as follows:

$$A_i = \sum_{j=1}^{J} E_j e^{-bt_{ij}} \tag{2}$$

where A_i is retail employment accessibility in TAZ i, J is the total number of TAZ, E_j is the quantity of retail employment in TAZ j, t_{ij} is the free-flow TAZ-to-TAZ travel time by automobile and b (here 0.2) is an empirically determined parameter that best explains variations in distance for all trips. A number of values were tested and a value of 0.2 selected based on visual comparison of different accessibility outcomes.

The PCA analysis shows that the observed variables are well loaded on the urban index principal component, which explains more than 70% of the total variance of the three observed variables in the analysis. The urban index is positively correlated with population density and with retail employment accessibility, but it is negatively correlated with median year built, which means newer areas—higher year—tend towards being less urbanized (i.e. more suburban).

Based on the results of the PCA, a map of the urban index for the Central Puget Sound region, roughly centered on the City of Seattle, was made and is shown in Fig. 1. Figure 1 demonstrates that the PCA generated a reasonable urban index that fits the urban–rural spectrum in the Central Puget Sound region at the U.S. Census block group level.

Research method

The analysis is performed using a discrete choice modeling approach, the multinomial logit (MNL) model, which has been in common use as a mode choice model for the past decades (e.g. Train 1978). The MNL model assumes each individual n associates a utility with each alternative mode i and that this utility is separable into an observable part, $\beta_i \mathbf{x}_{ni}$, and unobservable part ε_{ni}, where β_i are estimable mode-specific coefficients, $\mathbf{x}_{ni}$ are observable characteristics of the modes, trip makers, and environment, and the error terms ε_{ni} are independently and identically distributed type 1 extreme value (the Gumbel distribution). Furthermore, it is assumed that each individual trip maker selects the mode with the highest utility. This leads to the MNL model for the probability of individual n selecting mode i out of I modes:
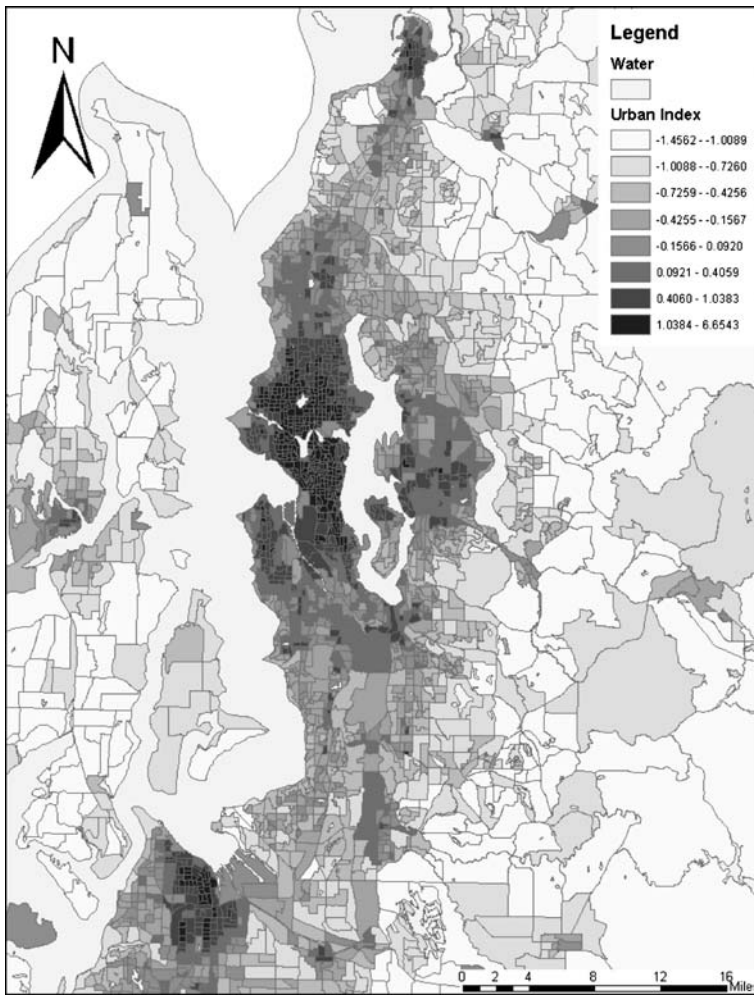
Fig. 1 Urban index of the Puget Sound region, Washington

$$P_{ni} = \frac{e^{\boldsymbol{\beta}_i \mathbf{x}_{ni}}}{\sum_{i'=1}^{I} e^{\boldsymbol{\beta}_{i'} \mathbf{x}_{ni'}}}. \tag{3}$$

However, there is no mode-specific information in this study, allowing us to drop the index i on the observed data, $\mathbf{x}_n$. In this case, the MNL model is unidentified up to a scale since it is sensitive only to differences in utility. One utility must therefore be arbitrarily, and without loss of generality, fixed and is most conveniently set to zero. We elect to use the *Automobile* mode as this base case to which the others (*Walk*, *Bus*, *Bike*) must be compared. The coefficients of the model can therefore be interpreted through their impact on the log–odds ratio of each alternative to the base case *Automobile*, since

$$\ln \frac{P_{ni|i \neq 1}}{P_{n1}} = \ln \frac{e^{\boldsymbol{\beta}_i \mathbf{x}_n}}{e^{\boldsymbol{\beta}_1 \mathbf{x}_n = 0}} = \boldsymbol{\beta}_i \mathbf{x}_n. \tag{4}$$

The coefficients in this model are estimated using the method of maximum likelihood, which also provides standard errors of the estimates. In order to focus on the most statistically significant factors we restrict coefficients that are not significantly different from zero at the 0.1 level of significance.

The MNL model assumes that error terms of the alternative choices are independent of each other. This leads to a property called the independence of irrelevant alternatives (IIA). Multinomial logit models are therefore valid when the outcome categories are plausibly distinct (McFadden 1974). Hausman and McFadden (1984) proposed a Hausman-type test of the IIA property which we apply to test whether the IIA assumption holds.

Findings

Table 1 shows a descriptive analysis of the data where each independent variable has been cross-tabulated with the mode choice. About 75% of all short home-based trips—defined here as being within 1.40 miles (about 2.25 km) distance—were made by automobile and about 23% of the trips were made by walking. These mode shares differ significantly from cited studies in Europe. For instance, the study by Mackett and Robertson (2000) showed that walking accounted for 80% of trips less than 1 mile and walking accounted for 58% of trips less than 2 miles (3.2 km). However, similar to the European studies, it was found that bus and bicycle were rarely used for short trips (1.1% and 1.2% respectively).

Table 1 shows there is an increasing share of automobile trips and a decreasing share of other modes as age increases. Also, females have a higher proportion of short automobile trips than males. African-Americans and Hispanic Americans have a higher proportion of automobile trips and a lower proportion of walking on short trips. People with a college or graduate degree have a higher proportion of walk trips compared to other groups. Driver's license and the need of an automobile at work indicate that people are more likely to drive even for short trips if they can drive or are accustomed to driving. This is further supported by vehicle availability in a household. Also, a bus pass is associated with a higher proportion of bus trips.

Household characteristics show specific patterns in relation to the mode choice for short trips. As household income level increases, the share of automobile trips increases while the shares of walk and bus trips decrease. The length of residence indicates that proportions of walking and biking decrease as people live longer in their residence.

When individuals are accompanied by someone else, there is a higher proportion of automobile use while the proportions of other modes become lower. Trip purpose indicates that shopping and pick-up/drop-off are related to higher proportions of automobile trips. Non-automobile modes are found more frequently in school trips. Time of day also shows some patterns in mode choice, however, the variations are not substantial. Trip distance shows that the walk mode has the shortest average trip distance and the bus mode has the longest average trip distance. The activity duration associated with bus trips is substantially longer than for the other modes.

The individual's overall travel behavior within the day may also affect the mode choice for a particular short trip. Table 2 shows descriptive statistics for total travel within a day. These have been calculated by modes such that each column's mean and standard deviation use only individuals who made at least one short home-based trip with that particular mode. This means individuals can enter into more than one column if they made short trips with different modes.

Table 2 shows that people who used the bus for a short trip at least once in the day have the lowest average trip frequency (3.2 trips) while the other modes are similar to each other (5.6–6.0 trips on the day). The total travel time of the day is lowest for people who used automobile for at least one short trip during the day. It is about 10 min shorter (at 70 min) than for the other modes (which are close to 80 min). People who used the automobile for at least one short trip have the longest total travel distance on the observed day while those people who used the bus at least once for a short trip have the shortest total travel distance. Connect this with the average trip distance for bus trips which is the longest (see Table 1). Finally, neighborhood environment, described with the urban index (see Table 2) which measures the level of urbanization in the person's home neighborhood, shows that short bus trips are observed on average in more urbanized areas while short automobile trips are observed on average in less urbanized areas.

The estimated MNL model for a trip maker's choice of travel mode for a short home-based trip is presented in Table 3. It should be noted that the unit of analysis is the trip, not the individual. The model shows the log–odds coefficients compared to the *Automobile* alternative. The Hausman test (Hausman and McFadden 1984) indicates that the IIA

Table 3 Multinomial logit model estimation results for short trip mode choice

	Walk		Bus		Bike	
	Coef.	SE	Coef.	SE	Coef.	SE
Constant	3.805	0.431‡	−5.123	1.253‡	−2.444	0.702‡
Age	−0.016	0.005‡			−0.026	0.013
African American/Hispanic	−0.754	0.329†	−3.755	1.342‡		
Graduate/college degree	0.444	0.124‡				
Valid driver's license	−2.185	0.231‡	−3.741	0.578‡		
Bus pass			1.568	0.518‡	1.551	0.541‡
Length of residence <1 year	0.327	0.200				
Vehicle availability	−0.775	0.153‡	−1.478	0.563‡	−0.819	0.441
Married with no children	−0.373	0.188†	−2.240	0.735‡		
Married with children	−0.807	0.199‡	−1.200	0.613†		
Non-family household	−1.452	0.237‡			−1.802	0.690‡
Accompanied by another on trip	−0.453	0.130‡			−2.733	0.747‡
Going to school	1.431	0.435‡	1.740	0.755†	3.329	0.574‡
Shopping	−0.674	0.171‡				
Eat out	0.636	0.272†				
Social/recreational	0.975	0.158‡			1.929	0.418‡
Trip distance	−3.888	0.202‡	2.720	0.830‡		
Daytime: 9:00–15:29	0.608	0.142‡	1.206	0.527†		
Activity duration			0.005	0.001‡		
Total travel time in the day	0.006	0.001	0.008	0.005		
Urban index	0.422	0.053‡	0.628	0.146‡		

All coefficients are statistically significant at the 0.1 level. † for *p*-value <0.05, ‡ for *p*-value <0.01

Automobile is the base case

Number of observations = 2,737, Likelihood-ratio $\chi^2(37) = 1270.39$

Log-likelihood (LL) with constants only $= -1802.18$, LL at convergence $= -1166.99$, pseudo-$\rho^2 = 0.3525$

assumption holds for this model. The overall improvement in log-likelihood starting with a model with constants only is satisfactory, indicated by a pseudo $\rho^2 = 0.3525$. All presented coefficients are significant at the 0.1 level, and significance at the 0.05 and 0.01 level is indicated with a † and a ‡ respectively.

We first note that the individual's age is negatively associated with walking and biking on short trips. The effect is larger for biking. This indicates that older people are increasingly less likely to select walking or biking compared to automobiles as their age increases. The model is neutral with respect to age and bus trips when compared to automobiles. African American and Hispanic individuals are negatively linked with walking and bus trips, indicating a relative preference for driving automobiles or biking. Individuals with a college degree are positively associated with walking on short trips. Having a valid driver's license has a strongly negative association with walking and bus trips, but is neutral for biking versus automobiles. Bus pass holders are positively linked with bus and bike trips. Buses in the study area are equipped with racks for two bicycles, so it is quite common for bike riders to use buses for a part of their trip.

New residents are positively linked with walking compared to residents that have lived in their neighborhood for a year or more. Age is controlled for in the model and tests using age interactions revealed that this effect is not due to new resident's being younger, but rather that new residents of all ages walk more than long term residents. As expected, vehicle availability is negatively associated with walk, bus, and bike, indicating a strong preference towards an automobile when it is available. Married individuals show a negative association with walking and bus trips, and there are slight differences between married individuals with and without children. The presence of children in the family is linked with less aversion to bus trips and greater aversion to walking, than for married individuals without children. Also, multi-generational households or extended family households are even more averse to walking than single-person households. When a person is accompanied by someone else on the trip, there is an aversion to walking and biking.

The trip purposes are linked with the mode choice preference. Notably, going to school is strongly linked with the non-automobile modes, walk, bus, and bike. Shopping is only negatively associated with walking but is neutral for bus, bike and automobile. Eating out is positively linked to walking, indicating a preference to walk to a neighborhood restaurant. Social/recreational trips are strongly linked to walking and biking, indicating that these modes are perhaps primarily used for social/recreational purposes and less as general purpose transportation modes. Trip distance is naturally very negatively associated with walking, and trip distance is positively associated with bus trips. This indicates that for longer short trips, people tend to prefer the bus. This is natural since there is a cost involved with using the bus, both in terms of out-of-pocket expenditure and in terms of waiting at a bus stop, time which might be enough to reach a destination when the trip is short.

People prefer walking and using the bus during the daytime, but time of day was neutral with respect to the bike and automobile. This may in part link with an aversion to walking or using the bus at night which in turn may be related to safety concerns.

Activity duration is positively linked with bus trips. This is natural, since the cost in time, waiting for the bus and the relatively long in-vehicle time due to the bus having to stop at bus stops, means that people prefer to use the bus when the activity duration is longer so that the travel time is a lesser percentage of the total time. People that have larger total daily travel times show an association with the slower modes, walking and bus.

The urban index shows a significant positive relationship with walking and bus trips. This is expected since a more urbanized area offers more opportunities within short

walking distances. Also, a more urbanized area offers more frequent and denser bus connections and better service levels.

Discussion and conclusions

The study identified several factors that are associated with the mode choice of short home-based trips encompassing personal, household, trip, and neighborhood characteristics. The results reveal several implications for promoting non-automobile use on short trips. Like prior European studies, this study found that short trips are rarely made by bus and bike. This indicates the pedestrian walking environment as needing the most attention when promoting non-automobile travel on short trips.

This study also found that people are more likely to drive even for short trips if they can drive or are accustomed to drive. Mackett and Robertson (2000) reported that the automobile tends to be used for short trips to work because of its availability rather than because it is necessary. As shown in Table 3, higher vehicle availability reduces propensity towards all other modes on short trips.

Several studies investigated ways to discourage automobile use or to encourage other alternatives. For instance, Wright and Egan (2000) proposed strategies to discourage automobile travel and purchase focusing on people's self-image rather than their sense of public duty and pointed out that peer group pressure could be an important factor in changing attitudes among automobile users. Loukopoulos and Gärling (2005) proposed a social norms and peer pressure strategy ("no one likes to be seen as lazy or unfit") against the habitual driver not to use an automobile for short trips and combining this laziness message with a general health or self-esteem message. While these approaches have their own merits, it seems clear that they are not practical in making automobile users give up their vehicles as Mackett and Robertson (2000) argued.

Bus transit is usually not as convenient a travel mode due to substantial waiting time and planning caused by low level of service during non-peak periods, and limited door-to-door accessibility. This may apply especially to short trips, where the waiting time and the perhaps circuitous bus route will contribute significantly to the total travel time. Bicycles may not have a significant advantage over walking in terms of speed on a short trip but may bring a greater perceived traffic safety risk and concerns for bicycle theft means good bicycle racks are required at the destination. Also, bicycling may not be a good alternative in inclement weather conditions.

Congestion charging and parking regulations can have significant impacts on automobile use on short trips (Mackett and Robertson 2000). It is also necessary to pay attention to incentives on non-motorized modes or public transit as a complement to automobile disincentives. Such incentives may include pedestrian and bicyclist friendly street design, including pleasant and safe pedestrian and bicycle paths separated from automobile lanes, additional secure bicycle racks, improved door-to-door accessibility or proximity among non-home activity locations. Transit incentives could be reduced fares for short trips or within specific mixed-use activity corridors, transit stop locations that are close to the heart of activity centers, short enough distance between transit stations to maximize accessibility by pedestrians, and greater transit service level in major activity locations.

The relationship between the built environment and travel behavior has long been a controversial issue. Long distance travel behavior—including work trips—may not be significantly associated with the built environment or land use. However, the findings of this study seem to parallel several studies reporting that more urbanized neighborhood

characteristics or environment (high density traditional urban neighborhoods as opposed to suburban neighborhoods) are positively associated with walking (Berrigan and Troiano 2002; Craig et al. 2002). This study also found that bus use is more likely on short trips in more urbanized neighborhoods. This implies the built environment is an important factor in the mode choice for short trips and that higher-density mixed use development can be a valid approach to curb personal automobile use on short trips.

Those who have lived less than 1 year at their current residence have a higher propensity towards walking on short trips. Also, eating out and social/recreational activities were significantly associated with walking. These findings, along with the urban index, indicate that an environment that attracts people's interest and provides various activity opportunities can encourage people to walk on short trips.

Physical constraints in the aging process may make it difficult for seniors to walk even for short trips. It has been reported that there is a positive relationship between physical activity and psychological well-being in older adults (Morgan and Bath 1998). A significant increase in the number and proportion of older populations in many societies may require that special attention be given to quality walking environments as both an instrument to promote the physical activity of seniors and as a viable transportation alternative to automobiles on short trips.

However, seniors are may be more sensitive to the surrounding physical environment than younger people and may be more discouraged from walking due to negative externalities than other age groups. This may explain why older persons are found less likely to walk on short trips in this study.

It is interesting to observe that bus pass holders have a higher propensity towards both bus and bike for short trips. The study area has many bicycle enthusiasts and buses are equipped with bike racks. This finding indicates that people who use the bus or bicycle on a regular basis still utilize opportunities to ride the bus even on short trips. A persistency in travel behavior has been widely acknowledged. The efforts to reduce automobile use on short trips need to recognize potential links between long distance travel behavior and short distance travel behavior. Positive inter-modal transportation experiences may encourage more people to consider non-automobile use on short trips.

This study found that African-American and Hispanic populations are less likely to walk or select the bus for short trips. The study area has a significant level of racial segregation and these population groups tend to reside in urban neighborhoods often perceived as less safe. This may contribute to the findings. However, this study does not reveal how cultural issues are reflected in short trip behavior which may require further investigation since high-density urban areas where non-automobile short trips are more feasible are often occupied by ethnic or racial minorities in the U.S.

It has been reported that household type and travel behavior are related (Srinivasan and Ferreira 2002). In this study, we found that household type associated with lifecycle is found to be a significant factor in short trip mode choice. In particular, married people with children typically need to make more errands and require more rapid and instantaneous travel modes. Multi-generational family households may often have more group activities. Therefore, it seems natural to find lower propensity toward non-automobile use on short trips.

This study also found that trip purpose has a statistically significant association with short trip mode choice. Overall, non-work trips including school, eating out, and social/recreational trips have higher propensity toward walking. However, shopping trips are negatively associated with walking. Carrying heavy groceries or other shopping purchases may discourage people from walking on shopping trips.

This study found that trip distance still matters in mode choice for short trips, here less than 1.40 miles (2.25 km). However, this study was not able to fully analyze the effect of trip cost beyond trip distance or time since such information was not available. For short trips, many costs are expected to be insignificant, but parking cost could be an important factor, especially in the central business district.

Table 1 shows the average distance of walking on short trips was 0.41 miles (0.66 km) whereas the average distance of automobile use was 0.79 miles (1.26 km). The bus had the longest mean distance of 1.06 miles (1.70 km). Table 3 confirms that as trip distance increases, people are less likely to choose walking. Other metropolitan areas may have a different distance threshold point. However, identifying mean walking distance on short trips may be useful in developing strategies to encourage walking on short trips, e.g. for placement of businesses or services into mixed use areas, and could also link to transit stop location.

This study examined various personal, household, trip, and neighborhood factors that are associated with mode choice on short home-based trips. Travel behavior is consistent at a certain level. However, influencing people's choice of transport mode on short trips should be an important part of efforts encouraging the use of non-automobile transportation alternatives.

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