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Potential of converting short car trips to active trips: The role of the built environment in tour-based travel

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ABSTRACT

Objective: To better understand trip-chaining patterns and mode choice of various urban forms, this study examines the effects of land use on travel mode choice and analyzes the concept of neighborhood design in the substitution of short car trips by other transportation modes.
Methods: A 'tour' is defined as a home-to-home loop of individual trips, including all the stops made along the way. This paper develops tour-based, mode-choice models and conducts integrative assessments to determine the relative influences of the various factors associated with tour-based travel and activity space environments for short round trips.
Results: The short round trips most likely to require a car tended to be either commuting trips, trips involving heavy goods, or trips that link two or more stops. Transit trips for short-distance travel were likely to involve trip chaining, while most shopping trips comprised a single outing with no trip chaining. A key to increasing travel by walking was a concentration of retail shops and service providers near people's homes whereas street networks and a good regional accessibility encouraged cycling and transit use respectively, although potential spurious effects cannot be fully determined.
Conclusions: Policymakers in LA who hope to increase walking should focus on the concentration of business activity in a compact commercial core in residential areas, while transit agencies in LA should consider trends like chained trip-making and restructure communities and central places with much greater transit accessibility. These strategies for local urban design and regional accessibility are likely to affect people's decisions concerning travel mode mostly in non-work travel without intervening stops; therefore, personal vehicle use can be reduced more easily by focusing on trips for leisure time activities and personal business activities near residential locations rather than on work commutes.

1. Introduction

New Urbanism and Transit-Oriented Development (TOD) strategies, which are a recent American reform approach to development, attempt to encourage physical activity and reduce personal vehicle use. Despite the growing interest in such strategies, the policies that must be implemented to encourage drivers to find alternatives to short automobile trips are often ignored (Gärling et al., 2000). The 2009 National Household Travel Survey for California Add-on (NHTS-CA) shows that about 40 percent of all trips taken in the Los Angeles County were under 5 miles in round-trip length, and that driving was the mode for about 60 percent of these short

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trips. Some argue that we should target short trips in cars to reduce vehicle use (Hillman, 1998; Loukopoulos and Gärling, 2005) because short trips in cars cause disproportionate environmental impacts. Short trips in cars often take place before the engine has had time to warm up, and such trips generate additional emissions, such as carbon monoxide (CO) and volatile organic compounds (VOCs) (de Nazelle et al., 2010).

In addition to the associated environmental effects, reducing short trips in cars may be a viable way to reduce traffic congestion on local roads. For example, about 40% of all short trips started during peak traffic times and a half of these trips were taken by private vehicles in Los Angeles area (NHTS-CA, 2009).

Furthermore, these trips in cars can be replaced with walking and cycling, thereby providing needed physical exercise in the course of daily life (Handy, 1996; Greenwald and Boarnet, 2001; Cervero and Duncan, 2003). However, few studies have assessed the determinants that lead people to use cars for short trips or the neighborhood-scale interventions that could be designed and implemented to encourage changing the mode of such trips (Rodríguez and Joo, 2004). Taken together, these are all compelling reasons to focus on short trips because benefits will accrue as short, emission-intensive trips are replaced by non-automobile trips.

People use their cars for short trips for several reasons. A British study (Mackett, 2003) investigated short trips through in-depth interviews with 377 travelers who had taken short trips in their cars. His results attributed the use of cars for short trips to the transport of heavy goods and of children to school, the shortage of time, and the need for the car in a subsequent trip. Another study (Forward, 1998) reported that convenience made cars the dominant mode of travel and that the main disadvantage of walking was time constraints. In their surveys, Walton and Sunseri (2010) found that weather was the most common factor influencing the decision to drive a short distance. The additional factors that affect the choice of travel mode for short trips include the traveler's socio-economic and demographic status and preferences, the availability of a car, activity patterns, the purpose of the trip, the availability and quality of alternative modes, and the quality of the built environment of the neighborhoods that they live in or travel to (Kim and Ulfarsson, 2008; Loukopoulos and Gärling, 2005).

Among these factors, the built environment has been identified as a key factor that affects non-motorized travel (Badoe and Miller, 2000; Brownstone, 2008; and Handy 2005). The phrase "built environment" encompasses many factors, including residential density, the mix of land uses, the connectivity and scale of the streets, aesthetic qualities, and the transportation system. These factors are related to the basic strategies of New Urbanism and TOD that attempt to foster more compact development near transit stations by providing retail and employment centers within walking distance of high-density housing. Many urban designers and planners believe that neighborhood-level urban characteristics are strongly related to transportation modes. In particular, it is believed that the right urban form will promote alternatives to personal car use. This belief has been supported by the empirical literature using a mode choice model that hypothesizes that environmental characteristics act as incentives for travel behavior (Cervero, 2002; Chen et al., 2008; He, 2011; Kockelman, 1997; Zhang, 2004). These studies have provided useful insights in analyzing travel demand based on the traveler's preferences and the benefits obtained from the travel, as well as the costs, by examining individual trips, which is a trip-based approach.

Research into the fundamental influences on travel behavior has addressed the weaknesses and limitations of the trip-based approach, as findings have seldom reflected the linked nature of most travel, even though the choice of mode may be affected by both the outbound and return portions of the trip, and have raised key concerns regarding 'trip chaining' (i.e., travel involving multiple purposes and multiple destinations). Furthermore, research has indicated that trip chaining has been a growing phenomenon over the past decade and is becoming a significant part of people's daily travel because people increasingly tend to economize their amount of travel, given their limited time budgets and the high value of travel time savings (Hensher and Reyes, 2000).

Given this increased interest in trip chaining behavior, recent efforts have examined travel behavior through observations of the sequence of trip segments, which is called the tour-based approach. A "tour" links individual trips, including all the stops made along the way. Tour-based modeling can offer a more insightful understanding of the impact of land-use strategies on various travel behavior decisions by analyzing the sequence and combinations of all trips and activity patterns (Rasouli and Timmermans, 2014). For example, it is possible that land use diversity influences a person's decision to drive or walk short distances for a grocery shopping trip from home as a single outing that does not involve trip chaining. In that case, trip-based models can be used to show that the potential for shopping near the residential area may contribute to shifts in mode. However, when commuting by car to work and doing grocery shopping on the way, the likelihood of changing modes is very low. This difference can be revealed by using tour-based modeling that analyzes whole activity patterns.

This paper builds on previous studies and draws together behavioral and practical aspects of modeling individual tour-based mode choice. With the relative paucity of research investigating the effects of activity patterns and tour formation on mode choice, especially for short travel, this study was conducted to obtain a better understanding of the effects of tours to test the hypothesis that compact urban forms reduce short car travel. In so doing, the built environment characteristics of the origin (home) and destination (work or other activities location) areas of the tours, measured on different spatial scales, were considered.

The next section provides an overview of the literature reviewing the context of the theory of activity and travel decisions, and the tour-based approach to investigate the relationship between travel behavior and land use. This is followed by a description of the research methodology used to conduct the study and the main results. The next section presents the results and discussion. The paper ends with the conclusion section, which includes the study limitations and directions for further research.

2. Literature review

The tour-based approach is drawn from the activity-based approach that views travel as a derived demand for activities (Jones et al., 1990, Axhausen and Gärling, 1992). The approach focuses on sequences of travel behavior as the unit of analysis. It emphasizes the effects of employment status, gender and socio-economic characteristics of travelers, transport network and locational division on the spatial and temporal constraints of individual movement (Hägerstrand, 1970; Hanson and Huff, 1982; Pas and Koppelman 1987).

The literature demonstrates the wide use of the activity-based approach to explore activity chaining, duration, frequency, travel time, and location and transport-mode choice (Kitamura ,1988; Bhat and Koppelman, 1999; Bhat and Singh, 2000; and Bowman and Ben-Akiva, 2001). An important feature of this literature is the recognition of the nature of the interdependence between activity and tour mode choice.

One aspect of the activity-based approach is related to a close association between trip-chaining patterns and transport mode choice. de Nazelle et al. (2010) have shown that trip chaining constrains mode conversion and that chained trips are more likely to be taken via private vehicles. Similarly, Miller et al. (2005) have argued that the nature of a car trip is "chain-based". If a car is to be used for the outbound segment of the trip, then it must be used for the return segment of the trip because the car must be returned home. No such constraints, however, exist in the case of non-automobile modes, including transit or walking.

By contrast, relationships between trip-chaining patterns and built environment have also been investigated, but the findings are inconclusive. For example, Krizek (2003), and Shay and Khattak (2012) found that people who live in a highly walkable neighborhood tend to chain fewer intermediate stops and travel more often for non-work activities, while Maat and Timmermans (2006) found that higher densities result in a greater number of tours and more chained trips. Doubts exist as to whether the built environment itself affects tour formation or whether these frequent travels in higher-density communities may have been conducted via non-motorized means. The conclusions from these studies call for more rigorous examination of the interdependencies among activity patterns.

A few studies have employed advanced model techniques to analyze the causal relationship between the tour mode choice and the extent to which this relationship varies across the built environment. These studies have shown high densities, rich mixed land uses, and pedestrian-friendly designs of the home and work location to be important predictors of non-motorized mode choice. Frank et al. (2008) found that land use patterns of the workplace are important factors to determine tour mode choice for both mid-day travel and commuting. They assert that people typically decide their mode before leaving home, taking into account not only the first destination, but also the intermediate and return trips. Krygsman et al. (2007) have found a relationship between transport mode and trip-chaining behavior, but they noted that the evidence of this relationship is indeterminate when location factors of intermediate activities are considered. This result implies that true behavioral causality can be adequately explained by the activity-based approach only when the linkages between trips are properly incorporated into the analysis.

Advances in the study of travel behavior have led to the development of tour-based models that help improve our understanding of the effect of environmental attributes on travel behavior. However, relatively few studies have applied the tour-based modeling to investigate the relationships between land use and short travel, which are useful for approaches to encourage walking. In addition, most studies focused on home location but neglected the destination of work and non-work location. This study, however, assumes that the built environments at both tour origin and destination play an important role in mode choices to travel to activity locations, as early studies on travel behavior (Bhat and Koppelman 1999; Kitamura 1988; Bowman and Ben-Akiva 2001) indicated that individuals tend to optimize their entire activity patterns rather than just considering separate trip choices. Recently Lee (2015) found that local land use, walkability, and transit access had no impact on work-related tours, but that these factors are significantly related to non-work, chained trips. She concluded that there is more opportunity to use urban design policies to influence non-work tours than work tours, as work trips are a declining share of all travel. Our study is an extension of this work to investigate the relationship between activity patterns and land use, especially focusing on short, non-work trips. The current study suggests that analyzing the effect of environmental attributes on travel behavior will require the development and application of an integrated framework that extends tour-based models to include various land-use attributes such as residential, work, and other activities location.

3. Methods

3.1. Research design

In this study, a 'tour' is defined as a home-to-home loop that represents a chained trip, including all links within the loop, starting and ending at home. As discussed earlier, the choice of mode may be affected by both the outbound and return portions of the tour. Thus, the distance used in this study is the length of a tour that included multi-stop journeys within a single traveler's home-to-home loop. For this analysis, only home-based tours were considered, because these tours are likely correlated with the characteristics of a traveler's residential context and mode choice for the corresponding home-bound trips.

The data for individual travel behavior and any household variables came from the Los Angeles County sample, a subset of the 2009 NHTS-CA (Fig. 1). Land use patterns vary substantially within the Los Angeles County, which has the largest number of incorporated cities of any region in the United States, including the dense urban core of the city of Los Angles, several smaller cities, and many suburban neighborhoods. Los Angeles is also one of the most ethnically diverse urban areas in the United States (Strait, 2006). Focusing on a case study area in Los Angeles, this study explores the effects of land-use strategies on travel behavior in a diverse urban environment.

The sub-sample of these data used for the analysis included only persons who were 16 or older in order to exclude those ineligible for having a driving license. The analysis also included only persons who responded to the travel survey on a weekday (Monday through Friday) in order to analyze the complexity of daily travel patterns including commuting. These inclusion criteria afforded 6,834 tours performed by 4,231 respondents residing in 2,171 households. The median distance of a pedestrian round trip was 1.1 miles and the mean distance of walking trip was 1.7 miles with a 95^{th} percentile of five miles in the pooled sample. Therefore, we

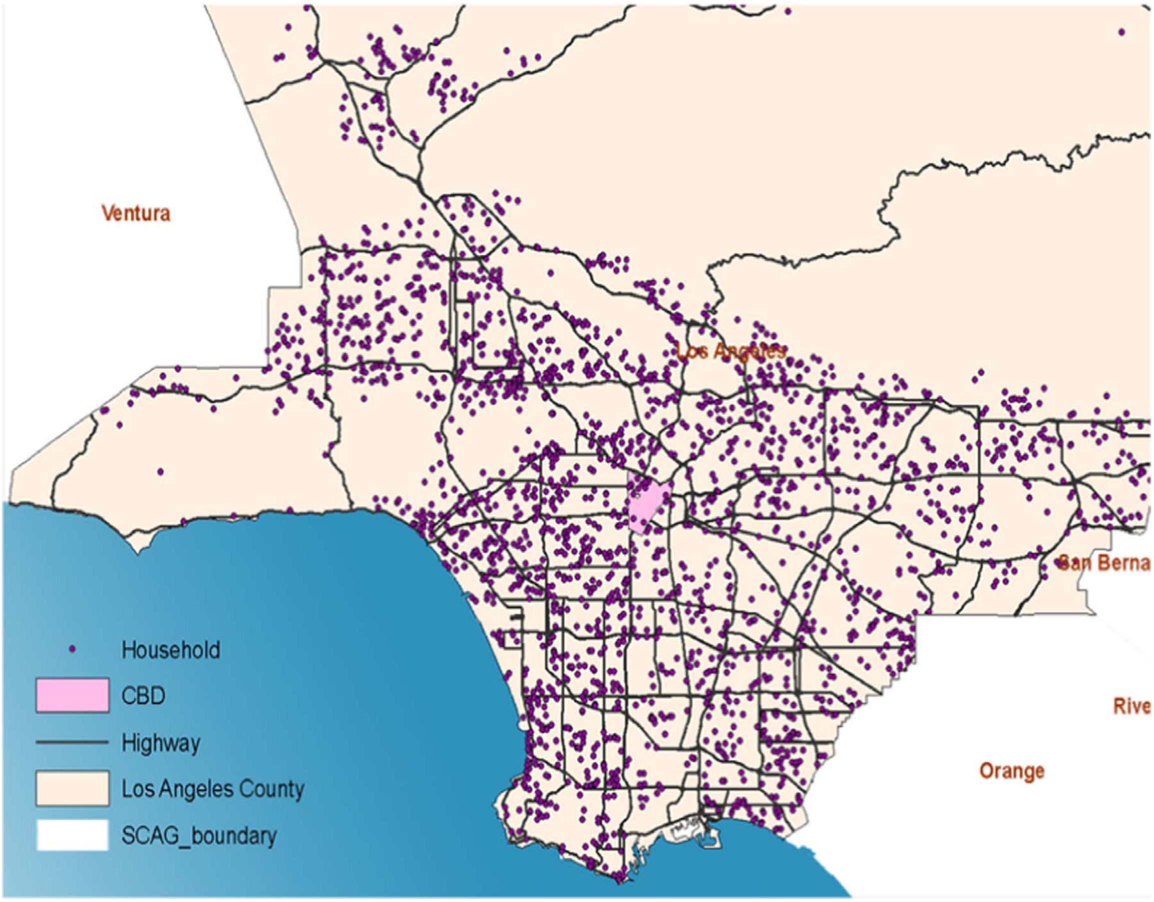

Fig. 1. Study Area and Household Location (Sample of Los Angeles County from the 2009 NHTS-CA Data).

defined 5 miles as the maximum distance and 2 miles as the average distance for a short round trip.

This value represents the round-trip length and 5 miles, the maximum distance for walking, is similar with the short trip distance investigated in the previously discussed UK studies that had 5-mile (8 km) distance (Mackett 2003, Maibach et al., 2009). The short trip distance investigated in the previously published American studies is shorter than the short trip distance in European studies. For instance, an American study (Kim and Ulfarsson, 2008) investigated short walking trips up to a maximum distance of 1.4 miles (2.25 km). Loukopoulos and Gärling (2005) looked at 2 miles as a walking distance for the U.S. sample. Another American study investigated trips shorter than 3 miles to determine how conversion of short automobile trips to other transportation modes reduces the emission of pollutants from vehicles (de Nazelle et al., 2010).

In this study, we presented two models, one with tours shorter than 2 miles and the other with tours shorter than 5 miles, to compare the effect of various personal, household, tour, and environment characteristics on tour mode choice for short-home-based trips.

3.2. The analytical framework

The framework of a conceptual model was developed in which travel decisions were tour-based, and the model was used to assess the choice of tour mode in one integrated framework. The assessment considered the characteristics of the built environment and the detailed, mode-specific travel time for each leg of the trip within a tour. This approach permits the modeling of the interaction among trip decisions that involve spatially displaced activities and simultaneously incorporate alternative-specific travel times, thereby reflecting the attractiveness of the alternative mode of travel. The other central component of this study that extended previous research was its inclusion of tests that indicate whether the built environment at trip destinations had a measurable influence on the mode that was chosen for a tour. This approach is used to test the hypothesis that the factors that facilitate mode choice are tour-purpose specific. Thus, interaction terms were included in the final model to elucidate how the effects of the built environment vary depending on the type of tour.

We expect travel patterns to vary depending on the purpose of a tour. We categorized the typology of activities to elaborate the different purposes of tours: 1) commuting, 2) shopping, 3) recreation, and 4) other discretionary activities (Gould and Golob, 1997). Commuting refers to activities involving work-related responsibilities or school tours and chains that include a journey to work or school. Shopping activities consist of visiting shops or stores to purchase or consume goods. Recreational activities comprise leisure activities performed during free time, including relaxation, exercising, dining, interacting with friends, or other social activities. Other discretionary activities include personal business tours, such as trips to the bank, routine visits to the doctor, and giving rides for children.

To assign a purpose to a multi-trip tour, the primary purpose of a tour was defined as the longest distance of all legs of the trip in the tour. In case of two equally long longest distances, the primary purpose was determined based on the following hierarchy: work > shopping > leisure > discretionary activities (Ye et al., 2007; Frank et al., 2008).

Four modes of travel were considered in this study, and the primary mode of the tour was determined based on the following priority sequence: drive > transit > bike > walk. In other words, if the drive mode was used for any trip legs within a tour, the primary purpose of the tour was defined as drive mode. This decision was made because this study focused on car use for any trip legs of a short round trip and examined alternative modes that attract drivers to leave their cars. The alternative modes were ranked in this way to reflect the anticipated consideration that travelers who viewed their travels strategically would use in evaluating their mode of travel.

Using the multinomial logit (MNL) models, we estimated the overall effect of the characteristics of the built environment on mode choice and the interaction effects between the built environment and the tour purpose, controlling for other factors that could potentially affect mode choice. The utility function used in this analysis was the sum of the utility of person *i* choosing mode *j* for the tour:

$$U_{ij} = V_{ij} + \varepsilon_{ij}, \tag{1}$$

$$V_{ij} = \alpha + \beta X_{ij} \quad \forall_j \in c \tag{2}$$

$$\beta X_{ij} = \beta_1 T + \beta_2 P + \beta_3 H + \beta_4 RB + \beta_5 DB \tag{3}$$

U_{ij} is the utility of the traveler *i*'s choosing option *j* for the tour;
V_{ij} is the systematic utility of traveler *i*'s choice for the tour;
ε is the non-systematic part of the utility for the choice;
α is the alternative-specific constant;
β is the vector of coefficients for the utilities;
c is the feasible choice set of modes;
T is the attributes of the tour that person *i* traveled (i.e., time, purpose, distance);
P is person *i*'s attributes (i.e., age, gender, ethnicity);
H is person *i*'s household variables (i.e., income, number of vehicles per person, family life);
RB is the built environment variable of the residential neighborhood where person *i* resides; and
DB is the built environment variable of the primary destination where person *i* traveled (in the case of a work tour, the destination is the person's workplace).

$$P(ij) = \frac{\exp(\beta' X_{ij})}{\sum_{k \in c} \exp(\beta' X_{ij})} \tag{4}$$

P(*ij*) is the probability of person *i* choosing a dominant mode *j* from a feasible choice set *c*, X_{ij} is a vector of explanatory variables, and β is the parameter to be estimated.

The explicit travel time for each leg of the trip was used to reflect the popularity of the alternatives. The automobile was treated as the base mode. The utility of other modes (transit, cycling, walking) relative to the private automobile depended on the relative travel time for the entire door-to-door trip.

Travel times were extracted from the origin-destination matrices of travel time via all modes, which were obtained from the regional transportation model of the Southern California Association of Governments (SCAG). The model includes travel-time skims as inputs for trip distribution, and these skims were available for the automobile and transit modes. To estimate door-to-door trip time for the transit mode, transit travel time was estimated by adding up walk access time, initial wait time, in-vehicle time, and transfer wait time. Thus, the transit travel time is comparable to the travel time by car, which provides high door-to-door accessibility. Walking and cycling travel times were estimated based on street network distances using ArcView Network Analyst in the geographical information system (GIS). The typical walking speeds and cycling speeds of adults were assumed to be 1.22 m/s and 5.36 m/s, respectively (Rodríguez and Joo, 2004).

3.3. Data and built environment measurements

Round trips shorter than 2 miles made up about 25% of all journeys undertaken in the Los Angeles County, but 43% of these were taken by car, compared to 52% by walking. Transit and cycling were rarely used for these trips, accounting for just 2.4% and 2.5%, respectively (Table 1). Walking was still the most common alternative to driving for extended round trips shorter than 5 miles. In the sample, driving accounted for 58% of all round trips shorter than 5 miles, compared to 37% by walking, and less than 6% by public transportation and bicycle.

To further facilitate the analysis, the tour types were cross-tabulated with the tour modes. Tours were divided into simple and complex categories. A complex tour included more than two trips with at least two intermediate stops, whereas simple tours involved

Table 1
Tour mode allocation by travel patterns (5 miles / 2miles).

	Tour type	Distribution	Car	Transit	Bike	Walk	Total
Tours shorter than 2miles	Complex tour	N	55	16	2	31	104
		% of complex tours	52.9%	15.4%	1.9%	29.8%	100.0%
		% of transportation mode	7.8%	41.0%	4.9%	3.7%	6.4%
		% of total tours	3.4%	1.0%	0.1%	1.9%	6.4%
	Simple tour	N	648	23	39	810	1520
		% of simple tours	42.6%	1.5%	2.6%	53.3%	100.0%
		% of transportation mode	92.2%	59.0%	95.1%	96.3%	93.6%
		% of total tours	39.9%	1.4%	2.4%	49.9%	93.6%
	Total	N	703	39	41	841	1624
		% of all tours	43.3%	2.4%	2.5%	51.8%	100.0%
Tours shorter than 5miles	Complex tour	N	293	35	6	50	384
		% of complex tours	76.3%	9.1%	1.6%	13.0%	100.0%
		% of transportation mode	20.4%	40.2%	11.3%	5.45%	15.4%
		% of total tours	11.8%	1.4%	0.2%	2.0%	15.4%
	Simple tour	N	1147	52	47	874	2120
		% of simple tours	54.1%	2.5%	2.2%	41.2%	100.0%
		% of transportation mode	79.6%	59.8%	88.7%	94.6%	84.6%
		% of total tours	45.8%	2.1%	1.9%	34.9%	84.6%
	Total	N	1440	87	53	924	2504
		% of all tours	57.5%	3.5%	2.1%	36.9%	100.0%

only one stop. Table 1 shows the different travel-mode allocations for chained trips, as used in simple and complex travel patterns. In complex travel patterns, most round trips shorter than 5 miles (76%) were taken by automobile, followed by walking (13%). The car was still dominant for simple tours, accounting for 54%. While public transit was more evenly shared between simple and complex tours, walking and cycling had a higher percentage of simple travel patterns.

Table 2 shows that most round trips shorter than 5 miles (85%) in the sample were taken for non-work purposes and that travel for work purposes represented a smaller portion. Thus, the purpose of tours shorter than five miles was generally shopping, recreation, or personal business. More than half of all complex tours were shopping tours that linked two or more intermediate stops. This finding is consistent with the findings of previous studies, which showed that shopping trips are often multi-purpose (Hanson, 1980; O'Kelly, 1981). Approximately 90% of the tours with recreational and other discretionary purposes were taken in simple travel patterns.

Table 3 lists the study variables, which were chosen to relate to the individual and travel characteristics and the built environment around home and destination of the tour. The characteristics of the built environment that were proposed to be relevant to active travel, i.e., transit, walking, and cycling, were defined, including residential density, land-use mix, street connectivity, the intensity of retail employment, and the accessibility of the transport network. These variables were selected based on the conceptual and empirical literature that identifies the objective components of environmental quality (Cerin et al., 2007; Frank et al., 2005; Saelens et al., 2003).

Table 2
Tour purpose allocation by travel patterns (2 miles / 5 miles).

	Tour Type	Distribution	Work	Shop	Recreation	Discretionary	Total
Tours shorter than 2miles	Complex tour	N	6	55	13	30	104
		% of complex tours	5.8%	52.9%	12.5%	28.8%	100.0%
		% of tour purpose	7.1%	11.4%	3.0%	4.8%	6.4%
		% of total tours	0.4%	3.4%	0.8%	1.8%	6.4%
	Simple tour	N	79	427	418	596	1520
		% of simple tours	5.2%	28.1%	27.5%	39.2%	100.0%
		% of tour purpose	92.9%	88.6%	97.0%	95.2%	93.6%
		% of total tours	4.9%	26.3%	25.7%	36.7%	93.6%
	Total	N	85	482	431	626	1624
		% of all tours	5.2%	29.7%	26.5%	38.5%	100.0%
Tours shorter than 5miles	Complex tour	N	31	213	39	101	384
		% of complex tours	8.1%	55.5%	10.2%	26.3%	100.0%
		% of tour purpose	18.2%	25.9%	6.8%	10.8%	15.3%
		% of total tours	1.2%	8.5%	1.6%	4.0%	15.3%
	Simple tour	N	139	610	533	838	2120
		% of simple tours	6.6%	28.8%	25.1%	39.5%	100.0%
		% of tour purpose	81.8%	74.1%	93.2%	89.2%	84.7%
		% of total tours	5.6%	24.4%	21.3%	33.5%	84.7%
	Total	N	170	823	572	939	2504
		% of all tours	6.8%	32.9%	22.8%	37.5%	100.0%

Table 3
Summary of variables used in the mode choice models.

Class	Variable	Description	Data Source
Individual Characteristics	Age	Age of respondents	NHTS-CA 2009
	Gender	Gender of respondents (female = 1 / male = 0)	
	Race	Race of respondents	
	Driver	Licensed drivers (driver = 1 / non-driver = 0)	
Household Characteristics	Income	Household income	
	lifecycle	Households with children = 1 / no children = 0	
	Veh/Pers	Ratio of vehicles to persons in a household	
Tour Purpose	Work	Primary tour purpose belongs to work	
	Shopping	Primary tour purpose belongs to shopping	
	Recreation	Primary tour purpose belongs to recreational/social activities	
	Discretionary	Primary tour purpose belongs to personal/family business	
Tour Time	AMpeak	Tour starts in AM peak: 7-9am (AM peak = 1)	
	PMpeak	Tour starts in PM peak: 4–6 pm (PM peak = 1)	
Tour Complexity	Complexity	Tour which has two or multiple stops (complex tour = 1)	
Mode Attributes	Driving time	Travel time for driving	SCAG Regional Transportation Model 2008
	Transit time	Travel time for transit	
	Walking time	Travel time for walking	Network Skim from GIS
	Cycling time	Travel time for cycling	
Land Use Attributes of Home/ Destination	HLU1	Street connectivity of home location	Network data 2008
	DLU1	Street connectivity of destination location	
	HLU2	Residential density of home location	Census data 2010
	DLU2	Residential density of destination location	
	HLU3	Land use mix of home location	Parcel data 2008
	DLU3	Land use mix of destination location	
	HLU4	Intensity of retail employment of home location	InfoUSA 2008
	DLU4	Intensity of retail employment of destination location	
	HLU5	Transit Accessibility of home location	Network data from SCAG InfoUSA 2008
	DLU5	Transit Accessibility of destination location	

The land-use mix variable was measured in terms of entropy (Cervero and Kockelman, 1997). Six types of land use were measured: residential, commercial, office, industrial, educational, and open space. This extensively used metric presents the level of integration of different types of land uses, such as residential and commercial uses within a 1/4-mile radius around each origin (home) and the primary tour destination. The value of higher mixed diversity will be close to 1, and zero indicates single land use.

$$\text{Land} - \text{use mix diversity} = \frac{-\sum_{j=1}^{J} P_j * \ln(P_j)}{\ln(J)} \tag{5}$$

where P_j is the proportion of the land development type of the j^{th} parcel, and J is the number of different types of land development.

The street connectivity based on a grid system was measured as the ratio of the number of intersections with four legs to the land area because grid patterns normally contain four-way intersections, where pedestrians may wish to cross the street and where traffic must slow down or stop. Multiple steps were taken to measure and improve the accuracy of the data. Because the study focused on only local street networks that were possibly used by pedestrians, all other non-local streets were removed from the dataset, including highways, freeways, expressways, and access ramps. After removing the nodes created at the street segments that did not directly connect to other portions of the local street network, nodes were created at the four-way intersections using the data on the centerlines of the street network.

To measure the concentration of retail stores and commercial services in the study area, employment data by industry sector were used based on the North American Industrial Classification System code from InfoUSA 2008. Using the geocoded locations of the business establishments, the distributions of retailers were mapped, and the total number of people employed in the retail establishments within a 1/4-mile radius around the locations of the origins and the destinations was calculated. The retail trade sector included establishments engaged in retail merchandising and after-sales services.

An area with good transit accessibility should have local buses that easily connect to many destinations where there is considerable employment, which implies many opportunities for working, shopping, and leisure activities. To measure transit accessibility, the travel times of local buses only were analyzed and those of rail travel were excluded due to the data limitation. Although the concept was limited by this exclusion of rail, the majority of transit trips in the sample were taken by bus and transit ridership depends heavily on access by buses in the Los Angeles region, accounting for 80 percent of transit ridership in 2009 (LACMTA, 2017). Transit accessibility is measured by transit travel time and the number of jobs served by the routes. We used a gravity-based model adopted from Hansen (1959). The transit accessibility of household location *i* was estimated by adding up the number of jobs in TAZs (Traffic Analysis Zones) $_j$ and travel impedance f (C_{ij}):

$$Ti = \sum \frac{E_j * \mathrm{f}(\mathrm{C}_{ij})}{\max T_i} \tag{6}$$

$$f(C_{ij}) = \exp(-bC_{ij}) \tag{7}$$

where

T_i = the transit accessibility index for household location i;
E_j = the number of jobs located in TAZ$_j$;
C_{ij} = travel time (in-vehicle + walk access + transfer wait + initial wait time) from Household i to centroid j; and
b = impedance factor = 0.0994.

The transit accessibility score was weighted by the maximum value of T_i, and it ranges from zero, indicating no access, to one, indicating the best access to employment. The employment data were taken from InfoUSA 2008 and the peak-hour travel time was measured using the local bus network acquired from SCAG's regional transportation model. The impedance factor for trips was calculated using the inverse of the average commuting distance, 10.06 miles, for the Los Angeles region in 2009 (NHTS 2009).

The mean and median sizes of a TAZ in the Los Angeles County are 1.57 and 0.43 square miles, respectively. Therefore, it was assumed that a person's walking and cycling trips are likely to be extended beyond one TAZ, although the resolution of TAZs was rather too gross to conduct micro-level analysis of detailed travel movements for suburban TAZs (Cervero, 2006). Some measures were correlated with each other. Principal Component Analysis (PCA) was used to discard redundant variables—home population density, destination population density, destination mixed land uses, and home transit accessibility. Among the 10 variables that were measured, six were selected for inclusion in the model on the basis of their contributions to the strength and significance of the results. The correlations among the final set of built environment variables were modest, ranging from 0.024 (destination retail intensity-home street connectivity) to 0.47 (home street connectivity-destination street connectivity).

4. Results and discussions

In this paper, several formulations were tested with all the explanatory variables and the possible interaction terms in the MNL models. The results from the MNL models for a tour taker's choice of tour mode for a short home-based tour are presented in Table 4. The unit of analysis is the tour, not the individual. Originally the data set included 1624 tours under 2 miles and 2504 tours under 5 miles. Because of missing values, mostly due to land use variables, some observations had to be dropped from the original sample. The final sample used for the estimations contains 1179 tours shorter than 2 miles (we call this the "short tour" model) and 1825 tours shorter than 5 miles (we call this "extended short tour" model).

The model shows the log-odds coefficients compared with the car alternative. The MNL model assumes that the odds ratio for a mode choice among three alternatives is independent of other alternatives. This assumption was tested using a Hausman test (Hausman and McFadden, 1984), the results of which indicated no statistical evidence to reject the independence of irrelevant alternatives assumption for all alternatives. The overall improvement in the log-likelihood over the null model was satisfactory, as indicated by pseudo-R^2 values of 40.4% (main effects) and 41.3% (interaction effects) for the 'extended short tour' model. Results for the 'short tour' model showed similar features but because of the smaller sample size of transit and bike trips, the overall model performance was limited and very few variables held statistical significance for the transit mode at the 90% confidence level. Therefore, only the model without interaction terms was used for the 'short tour' model.

4.1. Coefficients for household/individual characteristics

We first note that six primary factors related to travelers' possible preferences and constraints determine their mode choice for a short round trip: income, vehicle-to-person ratio, age, gender, driver's license, and lifecycle. As expected, those with a driver's license and more vehicles in their household were more likely to drive. Mode sharing for a short round trip depends largely on the availability of the car. In general, young travelers were more likely to use transit, and women were substantially less likely than men to cycle. Households with children were more likely to drive and less likely to cycle or walk. These findings are consistent with previous studies of mode choice at the trip-segment level (Cervero, 2002; Kockelman, 1997; Zhang, 2004). Notably, the difference between the results from the two models, 'short tour' versus 'extended short tour', can be attributed to the significance of the variables of household income. With increasing household income, the shares of transit trip decreases while the share of automobile trips increases in the case of 'extended short tour.' However, the effect of income on transit mode choice is not robust in case of 'short tour'. This shows that for longer transit distances, household's socio-economic characteristics are likely to dominate the decision of mode choice.

4.2. Coefficients for tour characteristics

The results provided insights into the constraints associated with tour characteristics. Because the study focused only on short round trips, fewer trips were commutes and proportionately more were made for shopping, recreation, and other discretionary purposes. People in the study preferred walking for recreational or discretionary activities in which commuting was not involved and

Table 4
Multinomial logit model estimation results for short trip mode choice.

		Short Tour (< = 2 Mile)						Extended Short Tour (< = 5 Mile)											
		Main Effects (Model 1)						Main Effects (Model 2)						Interaction Effects (Model 3)					
		Transit		Bike		Walk		Transit		Bike		Walk		Transit		Bike		Walk	
		Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.
Tour Characteristics																			
Purpose	Work	Ref.						Ref.						Ref.					
	Shopping	0.269		0.604		0.961	**	−0.911		−0.404		0.629	*	0.212		−2.295	**	0.706	*
	Recreation	−8.688		2.533	**	3.371	***	−0.210		1.433	**	3.100	***	−3.771		0.525		3.555	***
	Discretionary	0.884		−0.072		1.630	***	−0.178		−1.590	**	1.270	***	−4.145	***	−2.332		1.738	***
Tour Starts in AM peak		0.852		0.275		−0.047		0.828	*	0.480		0.064		1.068	**	0.538		0.065	
Tour Starts in PM peak		0.942		0.522		−0.032		0.048		0.479		−0.047		0.238		0.602		−0.033	
Tour Complexity		2.572	**	−0.501		−0.506		0.805	*	−0.367		−0.450	*	0.720		−0.282		−0.421	*
Person Characteristics																			
Age	16–24	Ref.						Ref.						Ref.					
	25–44	−2.305	*	−0.835		0.393		−1.105	*	−0.258		0.421		−1.083	*	−0.159		0.425	
	45–64	−0.605		−0.692		−0.158		−0.978		−0.301		−0.047		−1.163	*	−0.259		−0.028	
	65 +	−1.391		−2.594	***	−0.689	**	−0.893		−2.315	***	−0.659	**	−0.927		−2.238	***	−0.651	**
Female		−1.528		−1.353	***	−0.172		−0.293		−1.671	***	−0.184		−0.473		−1.595	***	−0.180	
Driver License		2.593	**	−2.479	***	−1.771	***	0.670		−2.161	***	−1.670	***	0.798		−2.239	***	−1.716	***
Household Characteristics																			
Income	Below $25k	Ref.						Ref.						Ref.					
	$25k-$50k	−0.192		−0.172		−0.289		−0.722		−0.319		−0.364	*	−0.850		−0.281		−0.362	*
	$50k-$75k	−2.333		−0.134		0.204		−1.613	**	−0.505		0.001		−1.683	*	−0.469		0.011	
	$75k +	0.026		−0.398		−0.162		−1.716	**	−0.729		−0.230		−1.555	*	−0.664		−0.237	
Lifecycle(child = 1)		−0.367		−2.271	***	−1.224	***	−0.962	*	−1.858	***	−1.069	***	−1.046	*	−1.935	***	−1.057	***
Vehicle/Person		−9.738	***	−2.206	***	−0.575	***	−4.780	***	−1.465	**	−0.531	***	−5.270	***	−1.476	**	−0.512	***
Tour Characteristics																			
Driving Time		0.018		−0.005		−0.017		0.030	*	−0.007		−0.025	**	0.027	*	−0.008		−0.025	**
Transit Use Time		−0.004		−0.003		−0.001		−0.005		−0.000		−0.000		−0.005	*	−0.000		−0.000	
Walking/Cycling Time		0.002		−0.013		−0.073	***	0.001		−0.014	**	−0.050	***	0.001		−0.015	**	−0.050	***
Built Environment																			
HLU1		0.068		0.029		−0.006		0.031		0.053	**	−0.001		0.047	*	0.043		−0.003	
HLU3		−0.881		1.094		1.053	**	0.681		1.167		0.806	**	−2.580	*	1.731		1.246	**
HLU4		−0.001		0.001		0.001		−0.001		0.000		0.001	*	−0.001		0.000		0.001	*
DLU1		−0.104		−0.011		0.029	**	0.000		−0.043		0.026	***	0.021		−0.029		0.037	**
DLU4		0.001		−0.000		−0.001		−0.000		−0.000		−0.000		−0.001		−0.001		−0.000	
DTSQ7		3.876		−2.858		0.346		3.150	**	−0.089		0.329		2.694	*	0.307		0.409	
Interaction																			
HLU3 * Recreation														5.005		−1.050		−0.201	
HLU3 * Discretionary														8.587	***	1.281		−0.989	
DLU1 * Shopping														−0.090		0.245	**	−0.004	
DLU1 * Recreation														0.056		0.207	*	−0.031	
Intercept		−1.313		2.403		2.887	***	−0.209		2.173	*	2.518	***	1.033		3.359	**	2.165	***
No. of Observation		1179						1825						1825					
Log likelihood		−643.9769						−933.6933						−919.4758					

(continued on next page)

Table 4 (*continued*)

	Short Tour (< = 2 Mile)						Extended Short Tour (< = 5 Mile)											
	Main Effects (Model 1)						Main Effects (Model 2)						Interaction Effects (Model 3)					
	Transit		Bike		Walk		Transit		Bike		Walk		Transit		Bike		Walk	
	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.
Chi-square (prob.)			723.20 (0.0000)						1268.11 (0.0000)						1296.55 (0.0000)			
Pseudo R-suare			0.3596						0.4044						0.4135			

Note: Coeff. = coefficient; Sig. : Significance ; Ref. : Reference; HLU1: Home street connectivity; HLU3 : Home mixed land-uses; HLU4 : Home retail employment intensity; DLU1: Destination street connectivity; DLU4: Destination retail employment intensity DTSQ7: Destination Transit Accessibility. * Statistically significant at 10%;** Statistically significant at 5%; *** Statistically significant at 1%.

their walking was limited to a single activity, such as socializing, leisure time activities or other activities that individuals engage in for pleasure and relaxation. The findings suggest shorter distances between recreational facilities/service providers and residences may contribute to increases in pedestrian travel, which is consistent with the New Urbanism concepts and ideas of mixed-use development (Ewing and Cervero, 2001).

The tours belonging to chains with multiple stops accounted for 15% of the tours in the sample of all round trips short than 5 miles. The results of the model show that the complex tours had significant and negative impacts on walking for short round trips. This supports the hypothesis that trip chaining is a barrier to the propensity to walk. In other words, if a traveler has a multi-purpose demand, he or she is less likely to walk.

On the other hand, tour complexity had a positive impact on transit mode choice. That is, transit trips were chained tours that linked two or more intermediate stops. This means that transit trips for short-distance travel are often multi-purpose. The study results conflict with a previous study's findings that transit users chain less than drivers do (Hensher and Reyes, 2000). While the previous study revealed that trip chaining is a barrier to using public transport, the present study results indicate that a difference arose when comparing public transport choice overall to car for long-distance versus short-distance travel. Transit users traveling shorter distances seem to make more complex trips involving different activities to minimize the fee and travel expenses incurred from trip taking, given the fact that transit agencies in LA employ flat fare systems that charge the same price regardless of the distance of travel. The policy implications of the current study refer to the need for the transit agencies in LA to consider trends like chained trip-making and to deliver services and the need for the planners to optimize their designs of communities and places (Cervero, 2004).

Upon testing, the impact of the start time of the tour was not as pronounced in the 'short tour' model, while AM-peak tours became more important for transit use when we account for the 'extended short tour' model. This is expected since longer transit trips tend to accommodate commute trips which are likely to be undertaken during peak time periods.

4.3. Travel time influences

Walking time was highly elastic (−1.881), meaning that a percentage change in walking time caused a large, negative percentage change in the probability that people would choose walking over the driving mode (Table 5). Travelers are most sensitive to changes in walking time for a short round trip. The results showed that walking is more sensitive to changes in travel time than to changes in the built environment. This finding makes sense because walking for transport purposes is often subjected to time constraints, even though increased proximity to shopping and other types of mixed-use areas can make up for the fact that walking is slower than other modes. Similarly, time was one of the most important predictors of transit use. A 10% reduction in transit time raises the probability of transit use by 5.54%, while an identical increase in the destination's transit accessibility increases the probability of transit use by 2.94% (Table 5). It seems likely that switching from driving to transit trips could be accomplished if transit travel time could be reduced.

4.4. Coefficients for the built environment

The likelihood of mode conversion to cycling, walking, and transit trips was estimated for the impact of the built environment, which was measured at both the home location and the destination location of the tour. Notably, the good transit accessibility of the destination has significant impacts on transit use, regardless of the tour's origin. This finding means that people are more likely to use public transportation when the tour's destination is more accessible to service and retail jobs. This might be because good transit accessibility to the employment site can encourage bus or transit commuting. Also, a densely urbanized central area with greater transit investment provides a denser bus network and more frequent and better transit service. That is, there may be an external benefit related to the transit infrastructure in some case, and this is primarily related to the economies of agglomeration due to improved transit accessibility (Beaudoin et al., 2016). The findings suggest that the goal of increasing transit use can be achieved more easily by focusing on a tour's destinations than on its origins (i.e., residential locations). From a practical standpoint, it is much

Table 5
The estimated elasticities of mode choice probability relative to independent variables.

	Variable	Car	Transit	Bike	Walk
Auto Availability	Number of vehicles per person	0.127	−3.552	−1.000	−0.281
Mode Attributes	Driving time	0.050	0.283	ns	−0.144
	Transit use time	ns	−0.554	ns	ns
	Walking/cycling time	0.664	0.700	ns	−1.881
Built Environment	Home street connectivity	ns	ns	0.581	ns
	Home mixed land uses	−0.090	ns	ns	0.237
	Home retail employment intensity	−0.017	ns	ns	0.048
	Destination street connectivity	−0.068	ns	ns	0.214
	Destination retail employment intensity	ns	ns	ns	ns
	Destination transit accessibility	ns	0.294	ns	ns

NOTE: ns = not significant.

easier to increase the transit accessibility of major destination areas (i.e., commercial cores and central areas) than that of home locations (Barnes, 2005).

The land-use mix and retail intensity where travelers lived increased walking activity, while street networks with fine grids appeared to promote walking to the destination. This finding indicates that although the ease of walking to the destination is one of the considerations that walkers consider, most walking activity is induced by the presence of convenience stores and grocery shops near people's homes. This is consistent with a previous study finding of more frequent walking for shopping trips with increasing neighborhood density (Forsyth et al., 2007). The findings also relate to the trip distance. Shopping trips on foot were more significant in the 'short tour' model than in the 'extended short tour' model. This supports the hypothesis that walking trips for shopping is more feasible within a short distance. This is natural since shopping trips often require carrying heavy goods. Presumably the shop was likely to be the last stop of a short round trip, given that most (89%) shopping trips comprised a single outing with no trip chaining (Table 2).

Bicycles may not have a significant advantage over walking in terms of shopping and discretionary trips, while biking was preferred for recreational activities. Cyclists seem to be most affected by their individual characteristics which accompany aging and the presence of children. Street connectivity of home location appears to be far more important for encouraging cycling, but the relationship between any other land-use factors (e.g., land-use mix) and the bike mode was relatively weak. Street connectivity with fine grids is associated with small block sizes in dense urban areas in LA. A fine grid could proxy for the existence of low-traffic routes containing many intersections where traffic must slow and come to a stop to allow the pedestrians to cross safely. By contrast, in a grid with large blocks the major arterials often carry fast traffic and both drivers and cyclists may have only one available route to their destination. Moreover, some caution may be necessary in interpreting the results for cycling tours since cyclists are also affected by the bicycle lane, steep slope, weather, street lighting, and speed and number of vehicles, which are closely related to the concerns of perceived traffic safety risk (Winters et al., 2012; Chen et al., 2012; Lee and Ko, 2014). As these effects are not dealt with in this paper, it is possible that the impact of land-use variables on cycling is overestimated or underestimated.

Interaction terms were added to analyze how the effect of the built environment may vary for different tour purposes. In recognition of the effects of parsimony, only the significant interaction terms were included in the model (Table 4). The results of interaction variables show that the built environment has different effects across tour types. Switching to public transport was the most likely choice for discretionary tours other than shopping and recreation when travelers lived in neighborhoods with prevalent mixed land uses. That is, multiple land uses in a neighborhood induced short transit tours for taking care of personal and family business. As these tours are less likely to require carrying heavy goods, the tour mode choice is relatively flexible in terms of using alternatives to driving a car. The choice of cycling increased with increasing intersection density at the destination if the dominant purpose of the tour was shopping or leisure. This result indicates, at least to some extent, that policymakers in LA can attract potential bikers more effectively by providing a good quality of street connectivity in shopping and recreation areas.

For cycling and walking, the marginal effects of the built environment on travel demand were modest to moderate in absolute terms. Elasticities fell in the range of 0.048 to 0.581. Consistent with the findings of Boarnet et al. (2011), having retail activities near people's homes had a marginal impact on the mode choice for walking. When other variables were controlled for, a 10% increase in street connectivity near people's homes increased cycling tours by 5.8%. Residences in mixed land-use areas and destinations with grid-like street patterns tended to average less automobile travel for a short round trip (Table 5).

Summarizing the results, we conclude that retail activity is important for predicting the conversion from cars to walking, and that chained trips matter. We also find that the measures of the built environment that facilitate walking behavior differ from those that encourage cycling or transit-use behavior. A key to increasing travel by walking was the concentration of retail shops and service providers near people's homes, whereas street networks with fine grids contributed to increases in cycling. The good regional accessibility of destinations appeared to be far more important than other local urban characteristics of the trip's origins for the use of public transportation. However, this finding should be interpreted with caution. The observed increase in the use of public transportation with increasing destination's accessibility could result from a spurious correlation with variables (e.g., destination mixed land uses, home transit accessibility) that were dropped by the PCA. While we did not focus on other factors, our study reaffirmed the importance of many of the demographic and socioeconomic characteristics of households and individuals used in other studies.

5. Conclusions

The literature is mixed regarding the potential effect on trip-chaining patterns and mode choice of various urban forms, specifically those under the concept of Smart Growth and New Urbanism. Researchers have debated the feasibility of alternative modes to car travel, but they have focused less on short round trips. Activity patterns and attributes of destination locations have often been ignored when assessing the travel impacts on mode choice. Thus, this study adds to the current body of knowledge by analyzing transportation mode choice for short round trips using highly detailed land use and travel data based on a tour-based modeling framework.

Consistent with previous studies, this study found that short trips are rarely made by public transportation and bike, which supports the importance of a good pedestrian environment in discouraging car travel on short trips. Among the determinants of a good pedestrian environment to promote walking, this study found that while street geometry may facilitate walking, the concentration of retail shops and other businesses serving the neighborhood was more important. The significant associations with mixed land uses, however, were limited for cycling and transit use. This finding might reflect that pedestrians are often motivated to walk in response to environmental attractions (e.g., a variety of attractive destinations, pedestrian-friendly window displays, and the presence of people on the streets), while bike and transit riders are more sensitive to the greater availability of route choices and the efficiency of network systems. This finding may be attributed to the fact that walking trips are often taken for recreation purposes during discretionary time, while other mode trips, including those via transit, often occur for transportation purposes.

Trip chaining matters, although the majority of short round trips consist of non-chained trips. The short round trips most likely to require a car tend to be either commuting trips, trips involving heavy goods (e.g., shopping trips), or trips that link two or more stops. The findings showed that travelers needing the comfort and flexibility of the automobile in facilitating intermediary stops on the trip are more likely to drive. In comparison, the majority of walking trips for shopping were conducted as a single outing that does not involve trip chaining. This is consistent with the findings from two previous studies (Krizek, 2003; Lee, 2016) which reported that residents in a compact neighborhood tend to leave home more often and take fewer chained trips for non-work activities during a day. The results from these studies confirm the concept that urban design with close proximity to shop facilities will promote walking.

The findings of this study offer insights for policymakers and practitioners in LA who hope to reduce the number of cars on the road by shifting car travel to transit and non-motorized modes. The evidence suggested that both the regional-scale accessibility approach and the neighborhood-scale land-use approach should be coordinated. The majority of walking travel in the Los Angeles region was undertaken within an approximate five-mile round-trip distance. Although the five-mile distance might be too far to accommodate walking travel, it might be appropriate to implement intervention strategies to leverage mobility. Considering that travel time and convenience (i.e., frequent and accessible transit services) appealed most to transit riders, providing competitive transit service satisfying these two factors will facilitate a mode shift to public transportation.

Local land-use policy might enhance commercial concentration and mixed development by providing density bonuses, flexible parking requirements, and minimum floor-to-area ratio requirements or similar strategies, while regional accessibility might be improved by providing fast, reliable, and frequent transit service between neighborhood centers. In addition, price strategies regarding parking regulations and congestion charging has the potential to alter automobile use on short trips (Mackett and Robertson 2000).

Non-work tours that are mostly treated as single activities also need to be considered. Commuting travel was not associated with the built environment or land use. Given that majority of the short-distance tours related to recreational, personal business, and social activities were likely to be undertaken by walking and cycling, policymakers who hope to increase active travel in LA should focus on the mixed-use core of residential areas. The findings of this study seem to parallel other studies reporting that more compact and mixed-use neighborhood characteristics are positively correlated with active transportation (Handy et al., 2002; Frank et al., 2007; Marshall and Garrick, 2010). Based on these findings, we suggest that public entities provide a convenient pedestrian environment, along with sites for recreational and service facilities that are closer to residential neighborhoods.

While the results of this study provide important insights into the role of the built environment in shaping travel behaviors, this study has some limitations. First, this study used cross-sectional data that may not reflect true causal relationships. In particular, modeling the effects of land use on travel demand can always raise the issue of self-selection. This issue should be addressed by future analyses with longitudinal data collected at the individual level. Second, the results of the study are not robust as the statistical significance of the built environment measures changes between the models used. This is possibly due to spurious correlation with omitted variables given the fact that some of the correlated characteristics of the origin and destination were dropped by the PCA to handle multicollinearity. Third, this study assumes uniform quality of sidewalks and bike lanes throughout the street network. However, the sidewalk environment may vary depending on its designs and conditions, such as width, connectivity, parked cars, trees, curbs, and pedestrian volumes. These factors could affect pedestrians' perceptions about the level of safety and pleasantness of the walking environment (Lee, 2013). Moreover, our results did not take into account cycling infrastructure such as designated bike lanes on surface streets, bike racks, and level of traffic. Cyclists are affected by the quality of bicycle lanes and motor vehicle traffic (Lee et al., 2015). Given the fact that previous studies show that safety risks and concerns are significant deterrents to cyclists (Garrard et al., 2008), our estimates of the benefit of transferring to cycling in this analysis are likely to overestimate the true effects.

A final limitation is that our findings may have limited applicability beyond the study area for the following two reasons. First, some observed association between the built environment and travel demand may be strong for an LA sample but may be diluted when tested across all US cities, because there could be spurious relationships between variables due to random variation making the relationship appear to be stronger than it really is. Second, our sample was limited to Los Angeles County and therefore may have limited generalizability to other environmental settings. While physical environments differ between regions, it is likely that the effects on travel behavior found in this study will differ across regions. For example, commute distances generally exceed the available range of walking in North American metropolitan areas but this does not apply to some European or Asian cities. Moreover, fine-grid street networks were used as a proxy of urbanity in this study but this would not apply to some other cities that are not laid out in a block pattern. Nevertheless, the study results are compelling for the cities of western North America with sprawling, automobile-centric, urban spatial structures. Further research is needed to investigate how barriers to promote active transportation differ across regions.

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