Transportation
DOI 10.1007/s11116-016-9687-5

The built environment determinants of activity participation and walking near the workplace

Steven R. Gehrke[1] · **Timothy F. Welch**[2]

Abstract Investigating the built environment determinants of commuting behaviors to and from the workplace has long been of interest to travel behavior researchers. Specific attention has centered on examination of how smart growth policies encourage both trip-chaining and active travel. Yet, limited research has investigated the impact of the built environment on activity participation and pedestrian travel once the worker has arrived at his/her workplace. A research omission that exists despite the prospect that built environment densification and diversification within employment districts may encounter less opposition from the local community and commuter. Our study investigates these identified gaps by analyzing how the built environment near an individual's workplace as well as personal, household, and tour-related attributes relate to work-based sub-tour activity participation and walking for activity fulfillment. A bivariate selection model estimated the workplace built environment determinants of work-based sub-tour participation and the likelihood to initiate travel for these sub-tour activities on foot. Findings from this Portland, Oregon study revealed that design and diversity features predicted work-based sub-tour participation; while, the decision to walk to start a sub-tour was strongly associated with a workplace built environment characterized by a traditional neighborhood design and increased residential density.

Keywords Travel behavior · Built environment · Activity participation · Mode choice · Pedestrian

✉ Timothy F. Welch
tim.welch@coa.gatech.edu

Steven R. Gehrke
sgehrke@pdx.edu

[1] Department of Civil and Environmental Engineering, Portland State University, P. O. Box 751, Portland, OR 97207.0751, USA

[2] Center for Quality Growth and Regional Development, School of City and Regional Planning, Georgia Institute of Technology, Atlanta, GA 30332, USA

Published online: 24 February 2016

Introduction

Individuals face a host of time budget constraints limiting the activities they may conduct on a given day. Consequently, individuals prioritize certain daily activities and tend to select a travel mode that minimizes the travel time needed for activity fulfillment (Hensher and Reyes 2000). Individuals, therefore, typically prioritize subsistence activities that provide the financial means to pursue secondary activities, and travel to any out-of-home activity location via the fastest available travel mode. As a result, a majority of workers drive to their workplace during peak travel hours. Maintenance and discretionary activities, which are less constrained by a fixed schedule generally have a smaller impact on mode choice (Strathman et al. 1994). Yet, workers must also allocate time during their workday to conduct these temporally flexible non-work activities in order to achieve personal daily objectives and sustain a work-life balance. An inviting prospect for time-constrained commuters may be to walk to non-work activity locations during the workday, which may in turn reduce their likelihood of driving to other destinations during the rest of their day (Chatman 2003). By determining what built environment features influence work-based activity participation, urban planners may have another tool at their disposal to promote off-peak travel via non-automotive modes.

To date, a significant amount of travel behavior research has focused on better understanding the impact of the built environment on commuting behaviors to and from the workplace. However, the role of the built environment on travel decisions once an individual has arrived at his/her workplace has received inadequate inspection (Van Acker and Witlox 2011). Moreover, study of what workplace built environment features impact travel has remained scarce when compared to behavioral studies linking travel to the residential environment (Frank et al. 2008). This research gap exists despite many important transportation-land use motives for improving the pedestrian environment near employment districts. First, urban policies aimed at altering the built environment of a commercial center are less likely to meet local opposition than those increasing the density and diversity of activity locations within a residential neighborhood (Chatman 2003). Second, a more compact and complex workplace built environment would decrease the distance to non-work activity locations; consequently, making walking to perform the travel needed to fulfill non-work activities more competitive with driving. For these reasons, planning efforts to increase activity density, diversify activity locations, and enhance the design of these environments will likely increase both the attractiveness and feasibility of walking to participate in many non-work activities during the workday (Handy et al. 2002). A link made more important by the indication that individuals are less likely to choose a workplace based on its surrounding built environment; subsequently, an individual who is reluctant to reside in an urban environment may have fewer qualms working in a dense, mixed-use setting (Chatman 2003).

Built environments characterized by these smart growth principles are not only associated with increased pedestrian travel and activity participation, but have also been found to increase the likelihood of an individual to conduct complex daily tours with added activity stops (Maat and Timmermans 2006). By carrying out complex sub-tours near the workplace and during the workday, an individual may shift activity fulfillment to mid-day hours and avoid the burdens of conducting secondary activities during peak travel periods. While tour formation and complexity may largely be explained by personal and household demands, urban policy clearly cannot have the same influence on these compositional features as it may on changing the built environment (Strathman et al. 1994). As such, transportation research should strive to inform practice and policy of the built environment determinants of work-based activity participation and mode choice. Such examination of workplace accessibility via measurement of the built environment near a workplace will expand our understanding of commute-related behavior (Cao et al. 2008).

To address these identified needs, our Portland-based study investigates the impact of objective built environment features near the workplace on both sub-tour participation and the likelihood to initiate these work-based sub-tours on foot. Our hypotheses are that (a) individuals working in areas exhibiting higher levels of density, diversity, and design are more likely to perform a work-based sub-tour by walking and that (b) the decision to walk is deterred by increasing the number of sub-tour stops and encouraged by participating in certain types of activities (e.g., eating, shopping) along their sub-tour. By exploring this understudied area of commuter travel behavior, our study aims to offer policy and practice richer insight into the built environment determinants of achieving activity fulfillment during the workday by physically healthy and environmentally sustainable travel.

Literature review

The present transportation-land use evidence base has commonly examined the act of travel for activity fulfillment as a set of isolated trips independent of the travel decision to chain trips with multiple purposes (Krizek 2003). An analytic shortcoming in the literature that exists despite the fact that trip-chaining has long been understood as an important transportation phenomenon (Primerano et al. 2008). By analyzing travel as a sequence of trip segments between activity locations that start and end at the home (tours), researchers will gain a more robust understanding of travel behavior that is founded within an activity-based conceptual framework more appropriate for examining transportation policy (Ho and Mulley 2013).

Travel behavior research conducted at a tour-level has generally accepted trip-chaining as a result of individual, household, and built environment characteristics as well as tour and transportation system attributes (Noland and Thomas 2007). Past tour-based analyses have classified this travel pattern as a dichotomized decision where the travel needed for activity fulfillment is accomplished with no additional travel stops (simple) or multiple stops (complex) (Strathman et al. 1994; Bhat 1997). Tour complexity has further been identified as a simple count of the activity stops comprising a tour (Ho and Mulley 2013). No matter the classification, tour complexity has commonly been understood as a commuting travel behavior in which the frequency of observed activity stops is highest during the evening commute; characterized by fewer time constraints and higher opportunity availability (Jou and Mahmassani 1997).

In terms of socioeconomic status, an increase in traveler age has been associated with increased activity stop frequency on the work-to-home commute (Van Acker and Witlox 2011; Jou and Mahmassani 1997; Bhat and Singh 2000; Wu and Ye 2008). However, Chu (2003) found the opposite association when examining the impact of traveler age on work-based sub-tour activity participation. Meanwhile, analyses of tour complexity by gender have consistently shown that female travelers stop more frequently because of heightened marriage and household responsibilities (McGuckin and Murakami 1999; Cao et al. 2008). Expectedly, a commuter living alone has been found to make more complex tours for both work-to-home travel (Van Acker and Witlox 2011; Wu and Ye 2008) and work-based sub-tours (Chu 2003). A trend consequential of the limited prospect for individuals to share any maintenance activity involvement with other adult household members (Bhat and Singh 2000). Moreover, individuals with a greater annual household income have generally conducted increasingly complex tours (Strathman et al. 1994; Van Acker and Witlox 2011; Maat and Timmermans 2006).

Although these individual and household characteristics commonly drive the purpose, nature, and demand for travel (Hensher and Reyes 2000), built environment features at both the residence and workplace remain important determinants of activity participation (Ma and Goulias 1999). While the built environment determinants of tour complexity measured at the residential neighborhood have been often studied, far less attention has been given to its measurement at the workplace (Frank et al. 2008) or other out-of-home activity locations (Schneider and Pande 2012). Noting the important role of urban density and diversity, Maat and Timmermans (2006) found an increase in their density-mix index at the workplace was associated with greater tour complexity. Van Acker and Witlox (2011) created a built environment index describing the percentage of built-up surface near the workplace and found a positive relationship with increased activity participation during the home-based work tour. Focusing on the evening commute, Cao et al. (2008) found an increase in the number of eating-out establishments within 400 m of the traveler's residence was associated with increased activity stop frequency. Analyzing work-based sub-tours, Chu (2003) discovered employment density measured at the workplace had a positive relationship with activity participation.

Similarly, the workplace built environment features influencing the travel mode selected to fulfill out-of-home activities comprising a complex tour have received inadequate empirical attention. Smart growth strategies emphasizing density, diversity, and design of the built environment surrounding activity locations are believed by urban planners to discourage individuals from automobile use in favor of active travel (Cervero and Kockelman 1997; Chen et al. 2008). Increased employment density of the workplace built environment measured at both the US Census tract (Chatman 2003) and traffic analysis zone (Chen et al. 2008; Ding et al. 2014) has been found to decrease the likelihood of driving to work. Conversely, Zhang (2004) discovered a higher employment density at the trip destination led to an increased likelihood to walk or bike compared to driving alone. As for walking for transportation in association with density, the limited evidence has thus far only found increased household (Troped et al. 2010; Forsyth and Oakes 2014) and population (Troped et al. 2010) density near the workplace to have a positive relationship with physically activity.

Forsyth and Oates (2014) also discovered that an increase in the percent of commercial land uses within 800 m of the workplace, a diversity measure, was connected to an increase in daily walking distances. In turn, Cervero (2002) found a decrease in the likelihood of automobile mode choice was attributed to an increase in employment entropy measured at the workplace as well as an increase in the ratio of sidewalks to road miles, a design measure. Other studies associating design features to commute mode choice have noted an increase in average block size (Ding et al. 2014) and number of cul-de-sacs (Zhang 2004) near the destination increased the propensity of auto use. In a study particularly germane to our own, Frank et al. (2008) found an increased mixed use density, retail floor area ratio, and intersection density was connected to a higher share of walking for activity fulfillment during the workday. In all, the current evidence base has offered inadequate examination of how an individual's employment setting may enhance his/her proclivity for undertaking a work-based sub-tour and reaching these activity locations on foot.

Methods

Data sources

Transportation and built environment data for the three-county Portland, Oregon metropolitan region (Fig. 1) were used to investigate the built environment determinants of sub-tour activity participation and pedestrian travel near the workplace. Individual and household travel behavior data for commuters living in Multnomah, Clackamas, and Washington County were provided by the 2011 Oregon Household Activity Survey; a statewide household travel diary based on one-day activity-travel patterns. The primary purpose associated with each out-of-home activity conducted by a survey respondent was self-reported as was the travel mode chosen to arrive at each activity location. All activities performed by a commuter were initially disaggregated as individual trips, which were later sequentially linked in order to generate a dataset consisting of 2039 home-based work tours and 655 work-based sub-tours with complete home-to-home tour-level information. Table 1 provides descriptive statistics of the individual, household, and tour-related characteristics of the tour and sub-tour samples, respectively.

The dataset was augmented with several secondary data sources describing the built environment near all activity locations. Built environment data used to measure the density, diversity, and design of the activity stop environments were provided by the 2009 Quarterly Census of Employment and Wages Program, 2010 Longitudinal Employer-Household Dynamics Program, 2010 US Census, and 2010 Topologically Integrated Geographic Encoding and Referencing files.

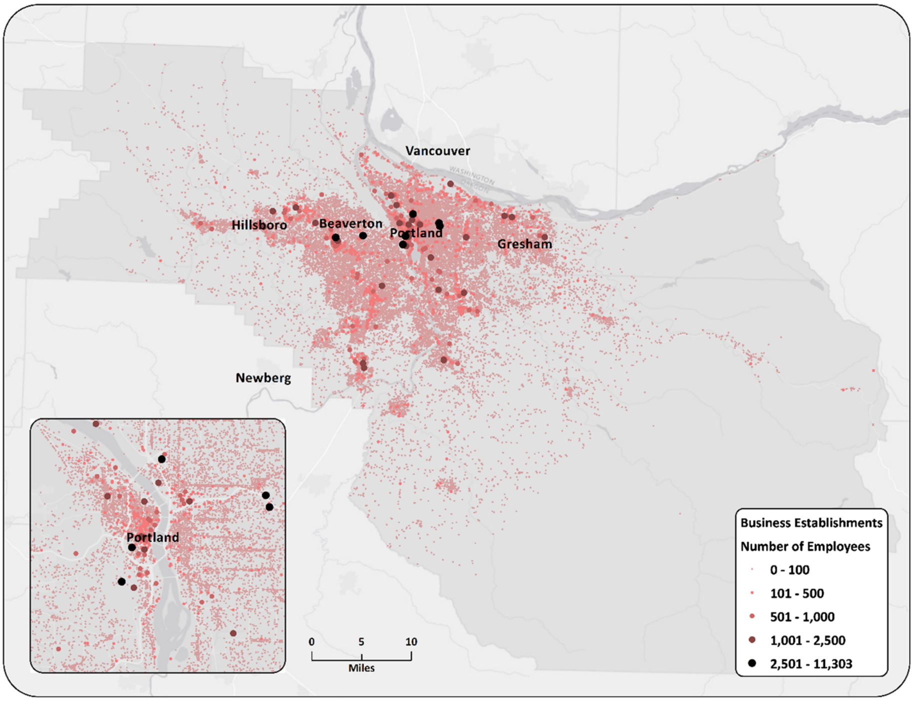

Fig. 1 Business establishment intensity in Portland, Oregon Metro Region

Table 1 Descriptive statistics of individual, household and tour-related characteristics

Variable	Home-based Tour (N = 2039)		Work-based Sub-tour (N = 655)	
	Mean	SD	Mean	SD
Individual Characteristics				
Age: 18–34 years	0.130	0.336	0.118	0.322
Age: 35–44 years	0.238	0.426	0.246	0.431
Age: 45–64 years	0.549	0.498	0.565	0.496
Age: 65 years or more	0.063	0.244	0.052	0.222
Gender: female	0.540	0.499	0.460	0.499
Education: bachelor's degree	0.359	0.480	0.397	0.490
Education: graduate degree	0.333	0.471	0.331	0.471
Employed: part-time	0.241	0.428	0.168	0.374
Employed: manufacturing	0.099	0.298	0.115	0.319
Employed: retail	0.062	0.241	0.038	0.192
Employed: service	0.552	0.497	0.530	0.499
Private vehicle ownership	0.239	0.427	0.296	0.457
Household characteristics				
Household size: 1 member	0.158	0.365	0.139	0.346
Household size: 2 members	0.347	0.476	0.365	0.482
Household size: 3 members	0.207	0.406	0.191	0.393
Household size: 4 or more members	0.288	0.453	0.305	0.461
Household income: less than $50,000	0.172	0.377	0.113	0.317
Household income: $50,000–$99,999	0.376	0.485	0.368	0.483
Household income: $100,000–$149,999	0.241	0.428	0.275	0.447
Household income: $150,000 or more	0.134	0.341	0.159	0.366
Child in household	0.379	0.485	0.400	0.490
Additional worker in household	0.710	0.454	0.701	0.458
Tour characteristics				
Tour stops before work	0.511	0.751	0.377	0.688
Tour stops after work	0.953	1.064	0.524	0.901
Initial tour mode: auto	0.871	0.335	0.823	0.382
Initial tour mode: transit	0.060	0.237	0.069	0.253
Initial tour mode: bicycle	0.050	0.217	0.082	0.275
Initial tour mode: walk	0.020	0.139	0.026	0.159

Activity classification and tour configuration

By assigning activity purpose to the trip segments comprising a tour, a more robust analysis that considers tour dimensions beyond activity participation may be conducted (Krizek 2003). However, a complicating prerequisite to any tour-based analysis has been the subdivision of activities into aggregated categories of purpose, which has been conducted a multitude of ways in the literature (Golob 2000). Most recent operationalization strategies have been activity-based, where an individual is assumed to schedule activity participation as an optimized daily travel pattern instead of an ad hoc trip-by-trip decision-making process

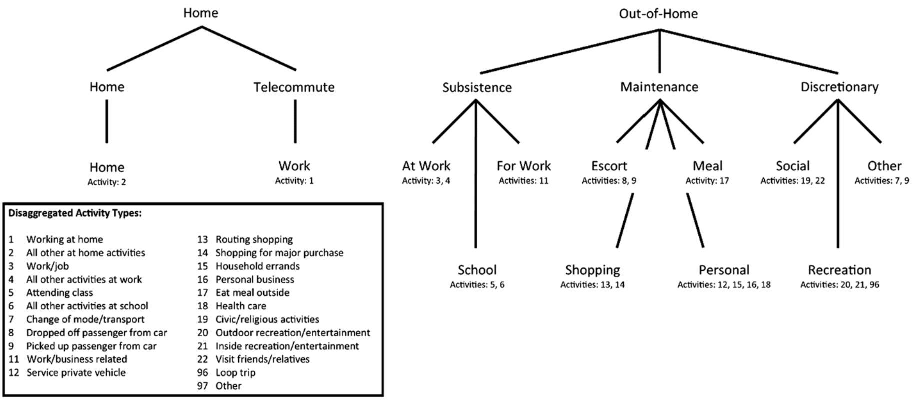

Fig. 2 Classification of activity purposes in the Oregon Household Activity Survey

without any time-saving foresight (Maat et al. 2005). A further inclusion of modern consumer theory has resulted in the popularity of a three-tiered classification system for out-of-home activities consisting of subsistence, maintenance, and discretionary divisions (Golob 2000). Although adoption of other schemes may offer additional insight into the sequencing of activity participation, an expansion of this activity type definition (Fig. 2) allowed a suitable examination of work-based sub-tour complexity and configuration.

Complexity of work-based sub-tours may be designated with two fairly straight-forward methods: (a) a count of activity locations visited on the sub-tour or (b) a set of nominal descriptions of activity types visited on the sub-tour (Ho and Mulley 2013). The former tour classification strategy allows distinction between simple (a single activity stop) and complex (multiple activity stops) sub-tours; whereas, the latter strategy provides discernment in the types of activities conducted on a sub-tour. Figure 3 illustrates the configuration of four work-based sub-tour descriptions based on this study's adoption of the three-tiered approach to out-of-home activity aggregation.

In this study, about one-third of all home-based tours had a work-based sub-tour (32.1 %). That is, a commuter arrived at his/her workplace, left the workplace to conduct one or more activities, and then returned to his/her workplace. Most work-based sub-tours (53.0 %) consisted of one maintenance-related activity; while, a smaller percentage of individuals undertaking these sub-tours participated in a single subsistence (18.0 %) or discretionary (6.0 %) activity. Nearly one-quarter of sampled work-based sub-tours had more than one activity location visited by the traveler; defined herein as a complex sub-tour (23.1 %).

Built environment measurement

Organization of activity purpose and tour configuration allowed analyses of the built environment influence near a commuter's workplace on sub-tour participation and the trip-level decision to walk for activity fulfillment. As mentioned, most transportation-land use studies have neglected any measurement of the built environment near the workplace despite the influential role this setting has on the daily activity and travel patterns of working individuals (Maat and Timmermans 2006). Of importance to travel behavior studies focused on walking has been the utilization of disaggregate built environment data to avert any ecological fallacy and provide greater spatial refinement for studying the link between smart growth principles and pedestrian activity (Handy et al. 2002). In response, the connections between walking to

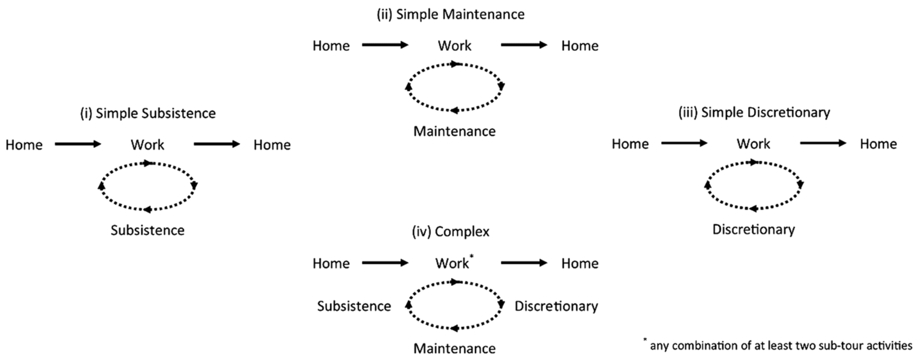

Fig. 3 Nominal configuration of work-based sub-tours based on three-tiered out-of-home activity classification

initiate a work-based sub-tour and various measures describing the density of employees and residents, diversity of jobs, and design of the street network surrounding the workplaces of Portland-area commuters (Table 2) was examined for this study.

To operationalize these measures, a synthetic zoning system of 264-foot grid cells was casted over the three counties, and a 0.25-mile Euclidean buffer was extended from the centroid of each grid cell. The adoption of a network of 264-foot grid cells, which illustrated the built environment located within a one-minute walk distance, was guided by land use modeling efforts within the Portland region (Metro 2011). Similarly, the quarter-mile search radius has been implemented in regional planning applications to reflect a pedestrian analysis zone, and has the added advantage of lessening the edge effects of a zonal system (Singleton et al. 2014). Twenty-five built environment measures were calculated within the quarter-mile buffered areas extending from the grid cell centroid and then attributed to the associated cell. A result of this measurement strategy was the creation of a spatially moving average that accounted for the built environment within each grid cell and its immediately adjacent cells (Maat and Timmermans 2006). Next, all workplace locations were assigned the built environment measurement attributed to the grid cell in which the site was located. Spatial information for all sub-tour activity locations, including an individual's workplace, were collected as part of the household travel survey. Table 3 provides descriptive statistics for the workplace built environment variables tested during our two-stage model estimation strategy.

Analytic approach

Work-based sub-tour participation and pedestrian travel mode choice were simultaneously modeled for the Portland study area. A two-stage analytic approach permitted the identification of built environment features that influence the decision to walk for sub-tour activity participation (Cameron and Trivedi 2005). All home-based work tours were initially analyzed to determine work-based sub-tour participation, while only those tours with a work-based sub-tour component were analyzed in the context of mode choice.

Adoption of a bivariate selection model approach, which has been commonly used in economic research (Franker and Moffitt 1988; Montmarquette et al. 2001) and more recently in transportation studies (Vance and Hedel 2007; Cao et al. 2008), enabled a simultaneous estimation of the determinants of the decision to participate in a work sub-

Table 2 Definition of workplace built environment measures used in analyses

Built environment variable	Measurement description
Density measures	
Activity density	Number of jobs and persons per square mile
Employment density	Number of jobs per square mile
Population density	Number of persons per square mile
Retail density	Number of retail jobs (NAICS = 44–45, 72) per square mile
Urban living infrastructure density[a]	Number of retail and service jobs per square mile
Diversity measures	
Employment entropy 1	11-class entropy measure based on all 2-digit NAICS jobs
Employment entropy 2	3-class entropy measure based on retail (NAICS = 44–45, 72), finance (NAICS = 52–53), and service (NAICS = 51, 54–56, 61–62, 71, 81) jobs
Employment-population balance 1	Ratio of jobs to persons
Employment-population balance 2[b]	Ratio of jobs to persons, normalized by study area ratio
Employment-population balance 3[b]	Ratio of retail jobs to persons, normalized by study area ratio
Design measures	
Block area	Mean area of street blocks in Euclidean buffer per square mile
Block density 1	Number of street block centroids per square mile
Block density 2	Number of US Census block centroids per square mile
Connected node ratio[c]	Ratio of 3-way and 4-way street intersection nodes to all nodes
Connectivity alpha index[c]	Ratio of observed circuits to maximum number of circuits
Connectivity beta index[c]	Ratio of street links to intersection nodes
Connectivity gamma index[c]	Ratio of observed street links to maximum number of street links
Connectivity cyclomatic index[c]	Number of route alternatives (circuits) between nodes
Cul-de-sac density	Number of cul-de-sacs per square mile
Intersection density	Number of 3-way and 4-way intersections per square mile
Intersection-Cul-de-sac ratio	Ratio of 3-way and 4-way street intersections to cul-de-sacs
Proportion of local roads	Proportion of local roads in Euclidean buffer
Proportion of primary roads	Proportion of primary roads in Euclidean buffer
Proportion of secondary roads	Proportion of secondary roads in Euclidean buffer
Street network density	Length of all roads in miles per square mile

[a] *Source* (Currans and Clifton 2015)

[b] *Source* (Ewing et al. 2001)

[c] *Source* (Dill 2004)

tour and walk mode choice with two equations. The first equation is a selection model estimating the propensity to participate in a work-based sub-tour, while the second equation is an outcome model measuring the probability a traveler will begin his/her sub-tour by walking (Toomet and Henningsen 2008):

Table 3 Descriptive statistics of workplace built environment measures

Built environment variable	Home-based tour (N = 2039)			Work-based Sub-tour (N = 655)		
	Median	Mean	SD	Median	Mean	SD
Density measures						
Activity density	14,792	31,455	40,396	12,895	24,152	32,961
Employment density	7913	26,052	40,729	5595	18,447	33,409
Population density	3788	5403	5337	3801	5705	5563
Retail density	780	3831	7183	581	2744	6087
Urban living infrastructure density	4479	16,789	26,849	3210	12,152	23,232
Diversity measures						
Employment entropy 1	0.458	0.417	0.200	0.439	0.411	0.201
Employment entropy 2	0.629	0.555	0.279	0.587	0.533	0.272
Employment-population balance 1	3.589	930	7965	2.547	557	4521
Employment-population balance 2	0.190	0.270	0.259	0.215	0.300	0.266
Employment-population balance 3	0.182	0.285	0.294	0.190	0.301	0.307
Design measures						
Block area	238,806	761,501	1625,331	157,108	733,963	1808,738
Block density 1	71	136	139	117	164	149
Block density 2	71	146	155	132	177	165
Connected node ratio	0.840	0.812	0.184	0.909	0.842	0.179
Connectivity alpha index	0.711	0.945	0.945	0.674	0.900	0.859
Connectivity beta index	2.222	2.347	0.515	2.220	2.367	0.583
Connectivity cyclomatic index	34	44	32	44	49	34
Connectivity gamma index	0.794	0.796	0.200	0.771	0.784	0.202
Cul-de-sac density	20	24	23	10	20	21
Intersection density	143	176	132	178	199	140
Intersection-Cul-de-sac ratio	2.78	9.018	16.630	2.800	10.472	18.551
Proportion of local roads	0.975	0.886	0.160	0.956	0.873	0.177
Proportion of primary roads	0.000	0.059	0.124	0.000	0.067	0.138
Proportion of secondary roads	0.000	0.051	0.094	0.000	0.056	0.110
Street network density	27	28	12	30	30	12

$$y_t^{S*} = \beta^{S'} x_t^S + \varepsilon_t^S \tag{1}$$

$$y_t^{O*} = \beta^{O'} x_t^O + \varepsilon_t^O \tag{2}$$

where y_t^{S*} is the latent tendency of a traveler t to select a work-based sub-tour, y_t^{O*} is the outcome of walking as an initial sub-tour mode, x_t^S and x_t^O are explanatory variables for the selection and outcome equations, and ε is the influence of unobserved variables on these selection and outcome equations. The relationship between the selection (work-based sub-tour participation) and outcome (walk mode to begin a work-based sub-tour) is shown below, where the outcome is only observed when the latent selection is positive:

$$y_t^S = \begin{cases} 0 & if\ y_t^{S*} < 0 \\ 1 & otherwise \end{cases} \tag{3}$$

$$y_t^O = \begin{cases} 0 & \text{if } y_t^S < 0 \\ y_t^{O*} & \text{otherwise} \end{cases} \tag{4}$$

The selection equations employ a probit link function and insert the resulting expectations $\lambda(\beta^{S'} x_t^S)$ into the following outcome equation (Greene 2013):

$$y_t^O = \beta^{O'} x_t^O + \gamma\lambda(\beta^{S'} x_t^S) + \eta_t \tag{5}$$

where $\lambda(\beta^{S'} x_t^S) = \phi\,(\beta^{S'} x_t^S)\,/\,\Phi\,(\beta^{S'} x_t^S)$ is the inverse Mills ratio, ϕ and Φ are the standard normal density and cumulative distribution functions, and η_t is the error term.

Two bivariate selection models were estimated to illustrate the influence of the workplace built environment on activity participation and walking near the workplace. First, a base model specifying the significant individual, household, and tour-related characteristics was estimated to identify the impact of non-planning variables on the two-stage process of participating in a work-based sub-tour and starting the sub-tour by walking. Then, a full model specification with all significant workplace built environment determinants was estimated to understand the additional influence of planning variables on the separate decisions. The final specifications used in these separate analyses were arrived at via a forward selection process in which the effect of each additional variable on the overall model fit was measured and tested against the reduced model.

Results

Estimation results from the two-stage models (Table 4) highlight the range of individual, household, tour, and built environment variables that were influential of both participation in a work-based sub-tour and the traveler's choice to walk for activity fulfillment. An examination of the base bivariate selection model results, which excluded workplace built environment measures, revealed several individual, household, and tour-related characteristics were significant determinants of work-based sub-tour participation. As expected, an increase in the number of stops made prior to arriving at (β = −0.313) and after departing from (β = −0.455) the workplace had a negative association with work-based sub-tour participation. While not a direct connection to activity substitution, the significance of these two tour-related predictors hint at time budget constraints limiting the number of activities an individual may conduct on a given day.

Also, the presence of an additional worker in the household (β = −0.189) was negatively related to work-based sub-tour participation, as was earning a household income below $100,000. Both findings are consistent with previous research noting the benefits of an additional worker to accomplishing household maintenance activities during the workday and increased consumption potential of households earning a higher income (Chu 2003). In terms of personal employment, working part-time (β = −0.175) and within the retail job sector (β = −0.337) had a negative relationship with the decision to take a work-based sub-tour.

Two other significant predictors of work-based sub-tour participation, which were also predictive of the second stage decision to walk, included gender (β = −0.140) and private vehicle ownership (β = 0.347). Female commuters were less likely than male commuters to undertake a work-based sub-tour; however, in the choice of travel mode for participation, female workers were more likely to begin their sub-tour via pedestrian travel (β = 0.129). On the other hand, commuters who owned a private vehicle (β = −0.156)

Table 4 Two-stage models of work-based sub-tour participation and walk mode choice

Independent variables	Base model			Full model		
	Estimate	SE	p value	Estimate	SE	p value
Work-based sub-tour selection						
(Intercept)	0.393	0.091	0.001	0.247	0.109	0.024
Female	−0.140	0.064	0.028	−0.154	0.065	0.018
Employed: part-time	−0.175	0.079	0.027	−0.159	0.080	0.047
Employed: retail	−0.337	0.140	0.016	−0.356	0.142	0.012
Private vehicle ownership	0.347	0.070	0.001	0.398	0.072	0.001
Household income: less than $50,000	−0.507	0.100	0.001	−0.529	0.102	0.001
Household income: $50,000–$99,999	−0.172	0.068	0.012	−0.163	0.069	0.018
Additional worker in household	−0.189	0.073	0.009	−0.205	0.074	0.005
Tour stops before work	−0.313	0.044	0.001	−0.311	0.045	0.001
Tour stops after work	−0.455	0.035	0.001	−0.447	0.036	0.001
Employment-population balance 3				0.224	0.105	0.034
Block density 1				0.001	0.001	0.001
Cul-de-sac density				−0.004	0.001	0.003
Proportion of primary roads				0.658	0.246	0.008
Walk mode choice outcome	Estimate	SE	P value	Estimate	SE	P value
(Intercept)	0.570	0.064	0.001	0.231	0.115	0.045
Sub-tour class: simple subsistence	0.028	0.050	0.581	−0.028	0.047	0.547
Sub-tour class: simple maintenance	0.216	0.040	0.001	0.206	0.037	0.001
Sub-tour class: simple discretionary	0.156	0.074	0.035	0.179	0.067	0.008
Initial tour mode: auto	−0.379	0.043	0.001	−0.226	0.042	0.001
Gender: female	0.129	0.034	0.001	0.088	0.031	0.005
Employed: manufacturing	−0.222	0.052	0.001	−0.089	0.049	0.069
Private vehicle ownership	−0.156	0.037	0.001	−0.124	0.034	0.001
Population density				0.001	0.001	0.001
Employment entropy 1				−0.279	0.075	0.001
Block density 1				0.001	0.001	0.001
Connected node ratio				0.187	0.111	0.091
Model summary						
Inverse mills ratio	−0.042	0.044	0.332	−0.029	0.040	0.471
Observations (N)	2039			2039		
Adjusted R^2	0.244			0.365		

were also less likely to walk as their initial mode of travel during a work-based sub-tour. Intuitively, individuals who began their home-based work tour as a driver or passenger of a vehicle ($\beta = -0.379$) were less likely to walk on their sub-tour than workers who commuted via transit, cycling, or walking.

Linking the second-stage modal decision to tour complexity, an activity classification of the work-based sub-tour was examined. When compared to a multi-stop work-based sub-tour, two of the three single-stop tour classifications revealed a significant association with walking. If a traveler engaged in a simple maintenance sub-tour ($\beta = 0.216$, SE $= 0.040$), defined as a single stop for an activity such as shopping or eating, then that individual was 1.24 times more likely to leave his/her workplace by walking than if/she was to undertake a complex sub-tour. Likewise, a worker who left his/her workplace to conduct a simple discretionary sub-tour ($\beta = 0.156$, SE $= 0.074$) was 1.17 times more likely to walk to the first activity location. These tour configuration findings support a study hypothesis by illustrating that an individual performing a single maintenance or discretionary activity on his/her work-based sub-tour will be more likely to walk for activity fulfillment than if their sub-tour comprised multiple activity locations. The chaining of multiple activities along a work-based sub-tour is more likely to be initiated by a travel mode other than walking, which may be due to the practicality for linking certain activities together or time constraints of traveling between multiple non-work locations within a single sub-tour.

As expected, a commuter's workplace built environment also predicted sub-tour participation. Overall, the addition of built environment measures to the described base model improved the adjusted goodness of fit, while maintaining the relative contribution of the individual, household, and tour-related determinants of sub-tour participation and walk mode choice. Of the 25 planning-related variables tested in the full model specification, three design and one diversity measure of the workplace built environment had a significant connection to an individual's sub-tour participation. An increase in the number of city blocks and decrease in the number of cul-de-sac streets within a quarter-mile areal buffer, two measures reflecting a traditional neighborhood street design, were each associated with increased work-based sub-tour selection. Increased localized jobs-housing balance, another smart growth tenet, was also predictive of sub-tour participation. In regard to transportation access, a higher proportion of primary roads, which symbolize improved automobile access to and from an area, was associated with greater sub-tour activity.

After censoring the study sample to only include home-based tours with a work-based sub-tour component and controlling for individual, household, and tour-related characteristics, four features of the workplace built environment were found to influence the decision to walk. Both an increase in the number of city blocks and persons per square mile positively influenced the likelihood to walk. The former finding was also predictive of sub-tour participation and highlights a connection between smaller block sizes and increased likelihood for pedestrian travel; whereas, the latter finding may be indirectly reflective of the types of destinations (e.g., cafes, restaurants, and markets) found near employment sites that also serve an area with a denser residential population. In contrast, a workplace built environment characterized by a higher employment entropy was linked to a reduction in likelihood to walk. A finding which may at first appear counterintuitive; however, an individual may be less inclined to walk if his/her workplace is located near an increasingly diverse set of industries including nuisance land uses.

The full model estimation produced a goodness of fit that was superior to the base model without measurement of the built environment around the workplace. Although built environment characteristics were significant in both the selection and outcome models, the inverse Mills ratio was not a statistically significant predictor of the second-stage outcome. Therefore, the likelihood to participate in a work-based sub-tour was found to have no statistical influence on the propensity to begin the sub-tour via walking. However, adoption of the bivariate analytic approach enabled estimation of the actual outcome, which was the choice of pedestrian travel among those commuters who participated in a work-based sub-tour. A conceptually suitable strategy (Vance and Hedel 2007) to estimate the built environment determinants of activity participation and walking during a work-based sub-tour.

Discussion

After accounting for individual, household, and tour-related characteristics, the built environment of the workplace remains an influential determinant of a commuter's penchant for work-based sub-tour activity participation and likelihood to walk for activity fulfillment. In our activity participation analysis, the tested set of diversity and design features appeared to matter more than the density of the workplace; although, the jointly modeled decision to conduct this derived travel demand on foot was associated with measures of each aspect of the built environment. Sub-tour participation and pedestrian travel were influenced by the sociodemographic and economic attributes of the commuter, the number of stops and mode chosen for the home-based tour, and several measures of the built environment near the commuter's workplace. Interestingly, increased street block density, a measure synonymous with a traditional neighborhood design, appeared as a significant determinant of both increased work-based sub-tour participation and the choice to walk as an initial sub-tour travel mode. Also evident from this two-stage analysis was that the smart growth principle of land use mix presented a less clear picture concerning its relationship with an increase in work-based sub-tour participation and likelihood of walking for activity fulfillment.

In all, this study contributes to a limited evidence base by examining the observed workplace built environment determinants of work-based sub-tour participation. Previous studies investigating activity participation of commuters have largely concentrated on the individual and household factors impacting travel to and from the workplace, with less attention given to the determinants of at-work sub-tour activity. Commuters participating in more activities before or after work are less likely to perform a work-based sub-tour; therefore, providing insight into how the built environment near a workplace impacts increased sub-tour participation may be an initial step toward shifting non-work-related commuter travel to the non-peak periods. A next logical step is to investigate the substitution of peak-hour discretionary and maintenance activities to determine whether observed work-based sub-tour participation indicates more overall travel or a temporal shifting away from peak period travel. Looking forward, interest in transportation policies related to the sharing economy (e.g., bikeshare, carshare) will also increase the demand for work-based transportation research since less importance will be placed on an individual's commute mode as all travel modes may now be available near his/her workplace regardless of ownership.

Our study also bolstered an evidence base that has almost exclusively centered on understanding the link between the residential environment and active travel. Findings of our study on the connection between the workplace setting and walking have shed new light on how established policy tools available to planners and policymakers may be used to further encourage pedestrian travel. As evidenced by results of the statistical models, the built environment was a significant factor on the decision to travel by foot; a desirable work-based sub-tour travel behavior influenced by increased residential density. An intriguing finding since increasing the residential density of a commercial district may be a more politically palatable goal than increased commercial density within a residential neighborhood. Also, the connection between smaller block sizes and walking for work-based sub-tours supports the adoption of redevelopment plans aimed at converting commercial superblocks to more traditional neighborhood development patterns.

Limitations

Aside from the contributions of this study and potential for exciting extensions of related work, future efforts must address some methodological limitations inherent to this analysis. Alternative analytic strategies may more clearly recognize the hierarchical relationship between the built environment near a workplace and pedestrian travel, where omitted indicators such as weather conditions may be specified as individual level determinants in a more robust conceptual framework (Clark et al. 2014). Extensions of this study should account for intra-household interactions since the decision to participate in a sub-tour activity is likely reliant on various other household decisions and dynamics. Furthermore, the classification scheme for activity purpose aggregation and sub-tour description used in this study are only one such approach and may not be considered the most theoretically apt depiction. Yet, despite these and other potential shortcomings, this study has provided empirical insight into a set of workplace built environment determinants of work-based sub-tour participation and walking that may be influenced by urban planning policies promoting smart growth principles.

References

Bhat, C.R.: Work travel mode choice and number of non-work commute stops. Transp. Res. Part B **31**(1), 41–54 (1997)

Bhat, C.R., Singh, S.K.: A comprehensive daily activity-travel generation model system for workers. Transp. Res. Part A **34**, 1–22 (2000)

Cao, X., Mokhtarian, P.L., Handy, S.L.: Differentiating the influence of accessibility, attitudes, and demographics on stop participation and frequency during the evening commute. Environ. Plan. **35**, 431–442 (2008)

Cameron, A.C., Trivedi, P.K.: Microeconometrics: Methods and Applications. Cambridge University Press, Cambridge (2005)

Cervero, R.: Built environments and mode choice: toward a normative framework. Transp. Res. Part D **7**, 265–284 (2002)

Cervero, R., Kockelman, K.: Travel demand and the 3Ds: density, diversity, and design. Transp. Res. Part D **2**(3), 199–219 (1997)

Chatman, D.G.: How density and mixed uses at the workplace affect personal commercial travel and commute mode choice. Transp. Res. Rec. J. Transp. Res. Board **4473**, 193–201 (2003)

Chen, C., Gong, H., Paaswell, R.: Role of the built environment on mode choice decisions: additional evidence on the impact of density. Transportation **35**, 285–299 (2008)

Chu, Y.-L.: Empirical analysis of commute stop-making behavior. Transp. Res. Rec. J. Transp. Res. Board **1831**, 106–113 (2003)

Clark, A.F., Scott, D.M., Yiannakoulias, N.: Examining the relationship between active travel, weather, and the built environment: a multilevel approach using a GPS-enhanced dataset. Transportation **41**, 325–338 (2014)

Currans, K.M., Clifton, K.J.: Using household travel surveys to adjust ITE trip generation rates. J Transp Land Use **8**(1), 85–119 (2015)

Dill, J.: Measuring network connectivity for bicycling and walking. Presented at 83rd annual meeting of the transportation research board, Washington (2004)

Ding, C., Lin, Y., Liu, C.: Exploring the influence of built environment on tour-based commuter mode choice: a cross-classified multilevel modeling approach. Transp. Res. Part D **32**, 230–238 (2014)

Ewing, R., Dumbaugh, E., Brown, M.: Internalizing travel by mixing land uses: study of master-planned communities in South Florida. Transp. Res. Rec. J. Transp. Res. Board **1780**, 115–120 (2001)

Forsyth, A., Oakes, J.M.: Workplace neighborhoods, walking, physical activity, weight status, and perceived health: assessing the built environment. Transp. Res. Rec. J. Transp. Res. Board **2452**, 98–104 (2014)

Franker, T., Moffitt, R.: The effect of food stamps on labor supply: a bivariate selection model. J Public Econ **35**(1), 25–56 (1988)

Frank, L., Bradley, M., Kavage, S., Chapman, J., Lawton, T.K.: Urban form, travel time, and cost relationships with tour complexity and mode choice. Transportation **35**, 37–54 (2008)
Golob, T.F.: A simultaneous model of household activity participation and trip chain generation. Transp. Res. Part B **34**, 355–376 (2000)
Greene, W.H.: Econometric Analysis. Pearson Education Limited, Essex (2013)
Handy, S.L., Boarnet, M.G., Ewing, R., Killingsworth, R.E.: How the built environment affects physical activity: views from urban planning. Am. J. Prev. Med. **23**(2S), 64–73 (2002)
Hensher, D.A., Reyes, A.J.: Trip chaining as a barrier to the propensity to use public transport. Transportation **27**, 341–361 (2000)
Ho, C.Q., Mulley, C.: Multiple purposes at single destination: a key to a better understanding of the relationship between tour complexity and mode choice. Transp. Res. Part A **49**, 206–219 (2013)
Jou, R.-C., Mahmassani, H.S.: Comparative analysis of day-to-day trip-chaining behavior of urban commuters in two cities. Transp. Res. Rec: J. Transp. Res. Board **1607**, 163–170 (1997)
Krizek, K.J.: Neighborhood services, trip purpose, and tour-based travel. Transportation **30**, 387–410 (2003)
Ma, J., Goulias, K.G.: Application of Poisson regression models to activity frequency analysis and prediction. Transp. Res. Rec. J. Transp. Res. Board **1676**, 86–94 (1999)
Maat, K., Timmermans, H.: Influence of land use on tour complexity: a Dutch case. Transp. Res. Rec. J. Transp. Res. Board **1977**, 234–241 (2006)
Maat, K., van Wee, B., Stead, D.: Land use and travel behaviour: Expected effects from the perspective of utility theory and activity-based theories. Environ. Plan. **32**, 33–46 (2005)
McGuckin, N., Murakami, E.: Examining trip-chaining behavior: comparison of travel by men and women. Transp. Res. Rec. J. Transp. Res. Board **1693**, 79–85 (1999)
Metro.: State of the Centers: Investing in our Communities. Metro (2011)
Montmarquette, C., Mahseredijian, S., Houle, S.: The determinants of university dropouts: a bivariate probability model with sample selection. Econ. Educ. Rev. **20**, 475–484 (2001)
Noland, R.B., Thomas, J.V.: Multivariate analysis of trip-chaining behavior. Environ. Plan. **34**, 953–970 (2007)
Primerano, F., Taylor, M.A., Pitaksringkarn, L., Tisato, P.: Defining and understanding trip chaining behavior. Transportation **35**, 55–72 (2008)
Schneider, R.J., Pande, S.: How common is pedestrian travel to, from, and within shopping districts? Transp. Res. Rec. J. Transp. Res. Board **2299**, 11–21 (2012)
Singleton, P.A., Schneider, R.J., Muhs, C., Clifton, K.J.: The pedestrian index of the environment: Representing the walking environment in planning applications. Presented at 93rd annual meeting of the transportation research board, Washington (2014)
Strathman, J.G., Dueker, K.J., Davis, J.S.: Effects of household structure and selected travel characteristics on trip chaining. Transportation **21**(1), 23–45 (1994)
Toomet, O., Henningsen, A.: Sample selection models in R: package sampleSelection. J. Stat. Softw. **27**(7), 1–23 (2008)
Troped, P.J., Wilson, J.S., Matthews, C.E., Cromley, E.K., Melly, S.J.: The built environment and location-based physical activity. Am. J. Prev. Med. **38**(4), 429–438 (2010)
Van Acker, V., Witlox, F.: Commuting trips within tours: how is commuting related to land use? Transportation **38**, 465–486 (2011)
Vance, C., Hedel, R.: The impact of urban form on automobile travel: disentangling causation from correlation. Transportation **34**, 575–588 (2007)
Wu, Z., Ye, X.: Joint modeling analysis of trip-chaining behavior on round-trip commute in the context of Xiamen, China. Transp. Res. Rec. J. Transp. Res. Board **2076**, 62–69 (2008)
Zhang, M.: The role of land use in travel mode choice: evidence from Boston and Hong Kong. J. Am. Plan. Assoc. **70**(3), 344–360 (2004)

Steven R. Gehrke is a Ph.D. candidate in Civil and Environmental Engineering at Portland State University. His research investigates the interactions between the built environment and travel behavior, with a focus on active modes of transportation.

Timothy F. Welch is an Assistant Professor with the School of City and Regional Planning and the Assistant Director of the Center for Quality Growth and Regional Development at the Georgia Institute of Technology. His research focuses on transport economics, equity and forecasting, and transportation-land use interactions.