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Safely Active Mobility for Urban Baby Boomers: The Role of Neighborhood Design

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Abstract
Many urban designers and researchers argue that walkable urban environments can encourage older residents' walking activities that benefit their physical health. However, walking also exposes older adults to safety risks, including due to traffic accidents. This study seeks to reveal the interactions between urban form and safety affecting urban baby boomers' walking behavior. Spatial analysis reveals traffic collision patterns in urban Boston neighborhoods, detecting hotspots around activity centers. Structural equation modeling, estimated on individual data collected from a mail-back survey and utilizing numerous measures of neighborhood urban form and accessibility, then attempts to reveal the causal, interacting relationships between neighborhood-level urban form, traffic crashes, and baby boomers' walking behavior. The analysis identifies significant effects of walkable urban forms (e.g., mixed use, well-connected streets, and good access to potential destinations) on older adults' walking. Yet, accessibility to retail, as well as traffic speed and volume, are positively associated with the traffic collision frequency. The results suggest more cautious approaches may be necessary for designing urban spaces for walkability and also call into question prescriptions based on the "safety in numbers" hypothesis.

Highlights

- We model the influence of neighborhood characteristics, traffic collision levels, and latent psychological factors on baby boomers' walking behavior.
- Walkable neighborhood characteristics, such as better land use diversity, intersection density, and accessibilities to retail shops, tend to increase walking activities.
- Accessibility to retail shops, as well as speed limits and traffic volumes, are associated with traffic crash frequency.
- Traffic crash frequency in a neighborhood is negatively correlated with older residents' walking activity levels.
- More cautious approaches may be necessary for designing urban spaces for walkability and "safety in numbers" hypothesis may need revisiting.

1. INTRODUCTION

The growing number of older adults in the USA continues to raise concerns about active and safe aging. While researchers in public health, urban planning, and related fields have emphasized the health and environmental benefits of physical activities, including "active travel" (e.g., walking and biking) (Boarnet et al., 2008), many older adults do not achieve recommended levels of physical activity (King et al., 1998). Traffic safety concerns may play a role. For example, the relatively lower crash involvement rates for older persons may reflect a risk aversion; older pedestrians involved in traffic collisions are much more vulnerable to serious injury or death than younger pedestrians (NHTSA, 2009). Thus, lower levels of walking by older adults may indicate an effort to reduce risk exposure (PEDSAFE, 2004).

This situation poses a potential dilemma. Urban designers, planners and others continue to advocate for urban design interventions as a way to encourage public and non-motorized transportation use. At the same time, local governments have developed specific plans to improve pedestrian safety, focusing on urban design interventions and education programs for drivers and pedestrians (Hunter & Hunter, 2008; New York City Department of Transportation, 2010). Are the dual goals of increasing older adults' walking levels and increasing the safety of the walking environment compatible? Despite considerable research on the relationship between the built environment and physical activity, in general, relatively little of this research has focused specifically on older adults. Furthermore, little is known about how urban form and safety interact to influence older adults' walking behavior. In a recent strategic plan on pedestrian safety, the U.S. Federal Highway Administration recognized the need for improved knowledge of the relationship between the built environment and walking, including effects on safety (Zegeer et al., 2010).

In this paper we examine, simultaneously, the inter-twined relationships among neighborhood form, traffic safety and older adults' walking behavior. Walkable urban forms can promote walking, but they are also often associated with higher traffic crash rates (Ewing & Dumbaugh, 2009; Moudon et al., 2011); these, in turn, are negatively correlated with walking (Owen et al., 2004; Bauman & Bull, 2007). A possible public health tradeoff then emerges: walkable environments might increase older adults' healthy living opportunities while at the same time increasing traffic collision risks (Miranda-Moreno et al., 2011). We explore these inter-relationships among urban-dwelling, "leading edge" baby boomers (55 to 65 year-olds) in the Boston metropolitan area. We focus on urban, as opposed to suburban, baby boomers because, while the boomers are a majority suburban cohort in the USA (Emrath & Liu, 2007), some evidence suggests boomers may be inclined to return to urban settings as they get older (Wieckowski, May 2010). Among other factors, baby boomers may prefer to live in less automobile-dependent settings as they age and driving becomes more difficult or impossible.

We examine the relationships between urban form, older adults' walking behavior, and traffic safety in Boston, MA. Specifically, we: (1) analyze the spatial patterns of traffic crashes, (2) use a mail-back survey to collect behavioral data and residential and mobility attitudes and preferences among urban-dwelling baby boomers, and (3) develop behavioral models which attempt to assess the causal impact of neighborhood-level urban form and spatial patterns of traffic crashes on baby boomers' walking behavior, based on individuals' approximate residential location, and controlling for relevant latent psychological constructs. Our ultimate aim is to improve neighborhood environments, so as to promote more environmentally benign, and physically active and safe mobility for older adults.

The remainder of this paper introduces the theoretical and analytical background for the research; outlines the conceptual framework and specific research questions; describes the setting and methods; and presents the results, implications, and shortcomings. A final section concludes.

2. THEORETICAL, EMPIRICAL AND ANALYTICAL BACKGROUND

2.1. Theory of Older Adults' Behavior and the Built Environment

In the field of gerontology, the relationship between older adults and environments has attracted significant attention. Lawton (1973) explains older adults' behavior with respect to two constructs: personal competence, a personal characteristic, conceived as the maximum expectable performance, such as biological health and motor skills; and, environmental press, representing the environmental demand on a person associated with personal needs or behavioral outcomes. Key to Lawton's model is the docility hypothesis, in which high personal competence implies relative independence from the demand of environmental press while low personal competence is associated with a higher level of vulnerability to environmental press. Thus, people with lower personal competence are more sensitive to the environmental demands. The natural process of aging reduces strength and endurance and increases physical frailty, likely increasing built environment-related constraints to walking, such as spatial distance. Therefore, the built environment tends to exert a greater influence on older adults than on their younger counterparts. The built environment may also interact with other relevant environmental dimensions, including personal (family and friends), suprapersonal (age or racial composition in a neighborhood), and social environments (norms or values in a society).

Lawton's theory is consistent with theories of individual travel behavior, in particular "net utility" theory (Maat et al., 2005). By this theory, people choose to walk based on the expected utility of the trip (i.e., whether the system gets a user to a desired destination) and the relative (to other available modes) disutility of realizing the trip, which includes time and costs – all of which may vary by the users' socioeconomic and demographic characteristics. The time component of a trip also includes two elements: actual and perceived (subjective) times, with the latter influenced by comfort levels (e.g., amenities, safety, etc.). In this way, we can formally understand the role that the built and social environments might play in determining walking behavior. The built environment determines the relative location of potential destinations of interest; at the same time, street and path networks impact actual distances and times – by determining, for example, directness of routes and number of stops, crossings, and other interferences. These same networks' conditions and other elements of the built environment, such as density and diversity of different land uses, impact perceived times – by affecting, for example, the overall walking experience (Jiang et al., 2012).

2.2. The Built Environment and Older Pedestrians

The relationship between the built environment and walking has been widely investigated. Density and diversity of land uses are oft-analyzed built environment measures, generally serving as a proxy for the intensity of overall neighborhood activities. Higher density may increase walking levels by, for example, shortening potential trip distances. More land use mix may exert similar influences, including by increasing the utility of a single trip tour by increasing the types of destinations available along the way and decreasing the distances between them. Density and diversity may also impact perceptions of the walking environment. In a recent meta-analysis of the now-extensive built environment-travel behavior literature, Ewing and Cervero (2010) find that walking is strongly related to land use diversity, employment and transit proximity, and intersection density.

For older adults, walking is particularly important, as the health benefits of physical activity for them are well-known. Moderate levels of daily physical activities reduce the risks of high blood pressure, heart disease, colon cancer, and diabetes, as well as depression (Nelson et al., 2007). Walking and cycling for daily travel offer an affordable, reliable and theoretically feasible way to achieve recommended physical activity levels (Pucher & Dijkstra, 2003). Nonetheless, approximately a third of older adults (55 and older) in the USA are physically inactive (King et al., 1998). Does research reveal a relationship between the built environment and older adults' physical activity? The evidence is mixed.

Analyzing data from a survey of individuals age 75 and older in Northern Virginia (USA), Lynott et al. (2009) find that older adults in urban and town areas tend to walk more for their trips more than those in rural or suburban areas, leading them to argue for the provision of compact, mixed-use communities to help satisfy the mobility needs of older adults who are aging in place. Li et al. (2005) find a correlation between density of employment and households and walking and Berke et al. (2007) find a statistically significant relationship between dwelling unit density and walk frequency. Clarke et al. (2009), on the other hand, in a 15-year panel study of older adults, find no effect of population density on walking difficulty. Satariano et al. (2010) find that older adults in mixed-use or commercial areas tend to spend more time walking, relative to those in residential areas. In contrast, Hall and McAuley (2010) find no significant difference in land use mix or land use diversity between older women who walk more than 10,000 steps per day and those who walk less than 10,000 steps. A related built environment dimension is accessibility to destinations, such as shopping malls, retail shops, and recreational places. The positive effect of accessibility to retail shops on older adults' walking has been consistently identified (Cao et al., 2010; King et al., 2003; Michael et al., 2006; Nagel et al., 2008). A qualitative study of 37 persons aged 55 and over identifies that well-maintained sidewalks, bike paths, and traffic control encourage physical activities. Some participants reported land use, landscape, and aesthetics as factors that encourage their activities (Strath et al., 2007).

The evidence on the accessibility to recreational places such as parks is mixed: Gómez et al. (2010) and King et al. (2003) find significant relationships; Hall & McAuley (2010), Michael et al. (2006), and Nagel et al. (2008) do not. Our own research of Boston's suburban baby boomers finds very modest evidence of direct effects of access to destinations on recreational non-motorized travel (Zegras et al., 2012). Similarly inconsistent results appear from analyses of effects of transportation infrastructure-related characteristics and older adults' walking activity, including: proximity to walking paths and trails (Hall & McAuley, 2010; King et al., 2003; Michael et al., 2006); proximity to transit stops (Gómez et al., 2010; Nagel et al., 2008); and street connectivity (Li et al., 2005; Hall & McAuley, 2010; Joseph & Zimring, 2007; Nagel et al., 2008; Satariano et al., 2010).

Overall, the empirical evidence remains inconclusive, if not contradictory. In reviews of relevant studies, Cunningham and Michael (2004) and Rosso et al. (2011) discuss causes of these mixed results: (1) lack of a theoretical framework, (2) limitation of cross-sectional data for causal inferences, (3) different measures and operational definitions of neighborhoods, and (4) differences in localities and subpopulations.

2.3. The Built Environment and Pedestrian Safety

Within Lawton's theoretical framework, safety represents an important potential environmental press. Generally, safety refers to freedom from dangers, which in our specific context can come from crime, traffic, and other sources (e.g., inadequate physical infrastructures, animals). Safety varies by individual perceptions and can certainly influence walking behaviors. In this particular research, we are concerned primarily with traffic safety and how it interacts with urban form to influence older adults' behavior. Most studies on the relationship between the built environment and traffic safety support the following framework: the built environment, including development patterns and roadway design, influences collision frequency and severity through its effects on the volume and speed of vehicle traffic (Ewing & Dumbaugh, 2009). For instance, a district with a higher population density tends to attract both more vehicular and pedestrian activities, which in turn likely increases the number of potential conflicts, and therefore, the number of traffic crashes. On the other hand, pedestrian fatality risk tends to be higher on wider streets that allow higher vehicle speeds (Garder, 2004; Rosen et al., 2011). Micro-scale design elements (e.g., traffic calming measures such as curb extensions, and raised crosswalks) potentially reduce traffic crashes and injuries by reducing traffic volume and speed as well as reducing pedestrian exposure to traffic in the roadway (Bunn et al., 2009; Herrstedt, 1992). Neighborhood-level urban form and land use characteristics also affect actual traffic crash rates: high population density, commercial uses, transit access, cross-street density, liquor license outlet density, and major streets are positively associated with vehicle-pedestrian crashes (Clifton & Kreamer-Fults, 2007; Hess et al., 2004; LaScala et al., 2000, 2001; Sebert Kuhlmann et al., 2009). Therefore, strategies that encourage densification, mixed land use, and public transit use may enlarge the total number of injured pedestrians, indirectly, through increasing pedestrian activities (Miranda-Moreno et al., 2011).

In terms of the safety effects on older adults' walking, once more, we find inconsistent evidence. Booth et al. (2000) find a correlation between perceived safety of walking and older adults' walking activities, while other studies find no such associations (King et al., 2000; Nagel et al., 2008). Using a composite perceived safety measure, Cao et al. (2010) find a negative association between perceived safety and walking, an unexpected result which they interpret as meaning that inactive older suburban adults tend to regard their neighborhoods as safer than urban neighborhoods. The results also vary depending on the dimension of safety considered. Balfour and Kaplan (2002), for example, examining physical activity, find no relationship with traffic safety, but a negative effect of inadequate lighting. King et al. (2000) also report that the effects of traffic, streetlights, and high crime are not significant, but unattended dogs are significantly associated with decreased physical activities. With particular emphasis on traffic safety, Hall and McAuley (2010) identify a significant difference in perceived pedestrian and traffic safety between active and inactive walking groups.

Finally, something akin to a network economy effect may exist: "safety in numbers," the idea being that as the number of pedestrians increases drivers become more aware of, and more cautious towards, pedestrians. Safety in numbers would imply that safety results, non-linearly, from pedestrian volumes (which may, in turn, be influenced by the environment) (Elvik, 2009; Jacobsen, 2003; Leden, 2002; Wier et al., 2009). Analytically, however, the safety in numbers hypothesis faces empirical and theoretical challenges, related to: confounding factors (e.g., intersection countermeasures), which may lead to false association between crash frequency and pedestrian volume; potentially reversed causality, by which safer conditions result in greater pedestrian volume, and not vice versa; and weak theoretical mechanisms. Finally, in assessing potential tradeoffs between the health benefits of "active travel" and the increased risks implied, we cannot ignore the increased physical vulnerability of older adults. Older adults tend to be more seriously injured when involved in traffic collisions, although they are also more cautious than other age groups (Zegeer et al., 1996; Harrell, 1991). The simultaneous deterioration of perceptual, cognitive, and physical abilities increases fatality rate of older adults (Gorrie et al., 2008; Oxley et al., 2006). Older adults also tend to be exposed to the risk of higher crosswalk crash rates (Zegeer et al., 2005). Leden et al. (2006) find that sufficient visibility, orientation, and clarity improve older adults' safety while crossing streets.

2.4. Analytical Challenges

The built environment-human behavior research realm faces the typical causality challenge: observing cross-sectional statistical relationships can only show correlation. Ideally, we would want a truly "randomized" experimental design, randomly distributing individuals into "treatment" and "control" settings and then comparing the behaviors of interest. Otherwise, we face threats to valid causal inference, a challenge which in the built environment-travel behavior literature is now commonly referred to as self-selection (Mokhtarian & Cao, 2008). Intuitively, self-selection refers to the phenomenon that people may choose a particular built environment (e.g., a "walkable" neighborhood) because of their predilection for walking. In other words, the presumed exogenous causal variable, the neighborhood, is actually endogenous, which can produce inconsistent and biased estimators. Mokhtarian and Cao (2008) review relevant technical issues and analytical approaches that have been employed to control for self-selection bias in built environment-travel behavior research.

Structural equation modeling (SEM) offers one analytical technique to control for self-selection, particularly when measures of individuals' relevant attitudes and preferences can be explicitly incorporated into the models. Full structural equation modeling simultaneously estimates measurement models, which extract latent variables (e.g., psychological constructs) from measured indicators (e.g., attitudes), and the structural models, which account for relationships among latent and observable variables (Golob, 2003). Therefore, SEM can help mitigate the self-selection challenge by enabling the consistent incorporation of attitudes and preferences in behavioral models and capturing complex influences between the built environment, attitudes, and travel behavior (Mokhtarian & Cao, 2008). An increasing number of studies have turned to SEM to investigate the complex relationships between the built environment and travel behavior with controls for self-selection. Nonetheless, most suffer from limitations. Some do not explicitly include attitudinal variables in the SEM models (Abreu & Goulias, 2009; Liu & Shen, 2011), which weakens the self-selection control. Other analyses incorporate attitudinal variables, but not with complete SEM; extracting latent variables as fitted values of factor analysis on indicators, rather than simultaneously estimating the structural and measurement equations (Cao et al., 2007; Bagley & Mokhtarian, 2002). We recently employed full SEM – incorporating attitudes and residential choice, to control for self-selection and to account for direct and indirect effects among exogenous and endogenous variables – in a study of baby boomers travel behavior in suburban Boston (Zegras et al., 2012). We employ a similar method here.

3. CONCEPTUAL FRAMEWORK AND RESEARCH QUESTIONS

Figure 1 depicts our conceptual framework relating neighborhood-scale urban form, traffic crashes, socio-economic/psychological characteristics, and older adults' walking behavior. We expect urban form – measured by land use, transit supply, and road network characteristics – to influence traffic crash frequency and older adults' walking behavior. We also expect neighborhood-scale traffic crashes, measured by the total number of annual traffic collisions within a neighborhood, to affect walking behavior and latent psychological characteristics, including safety concern and social norms supporting walking. Hence, we anticipate observing an indirect behavioral effect: urban form influencing traffic crashes and traffic crashes influencing walk behavior.

Do neighborhood physical characteristics influence traffic collisions? Neighborhood characteristics – such as density, mixed-use, accessibility to destinations and transit, and traffic speeds – are likely to influence the total number of traffic crashes by increasing traffic speeds and volumes, as well as pedestrian volumes. We expect to detect a clustering of traffic crashes in locations with characteristics that attract more motor vehicle and pedestrian activities. The spatial distribution of traffic crashes logically leads to the second question.

Do neighborhood characteristics and safety causally affect baby boomers' walking behavior? We anticipate that a neighborhood's physical characteristics influence residents' walking behavior by determining the total number, relative quality, and distribution of potential destinations (e.g., recreation, friends) and the relative travel costs (both actual, including time and money, and perceived, including comfort, safety, and relative enjoyment). We investigate two types of behavioral outcomes: utilitarian and recreational walking. With regard to neighborhood safety, we expect that better actual safety levels improve perceived safety levels and reduce safety concerns, thus encouraging walking. A neighborhood's physical characteristics may, then, directly and indirectly influence older adults' walking behavior.

4. SETTING AND METHODS

4.1. Context

The study area includes urban neighborhoods in four cities from the Boston metropolitan area: Boston, Cambridge, Somerville, and Brookline. One of the oldest cities in the United States, Boston, and its immediately surrounding cities, exhibits diverse urban forms, with a range of building types, street patterns, and land use configurations. While it has a relatively well-developed public transportation system compared to other metropolitan areas in the USA, Boston's levels of public transportation service still vary considerably across the urban area. Hence, the urban setting alone offers a reasonably heterogeneous context in which to examine how the built environment influences older adults' travel behavior.

4.2. Survey Design and Data

To collect socio-economic and behavioral information on 55-to-65-year-old baby boomers, we administered a mail-back survey in October 2010. The sampling frame was mailing addresses (purchased from USAData, a commercial data vendor) for residents 55 and older of urban neighborhoods in the Boston metropolitan area. We randomly sampled 7,000 households from the sampling frame and sent those households a mail-back household survey, including two booklets per household. The information collected through the survey included: (1) socioeconomic and demographic characteristics, (2) weekly behavioral characteristics (trip frequency by travel modes, purposes and social activities), (3) travel and residential choice-related attitudinal and preferences, and (4) levels of residential satisfaction. The survey instrument was specifically designed to include psychological factors, to enable the inclusion of latent characteristics via full SEM to help control for self-selection. In total, 1,005 households, including 1,401 individuals, returned completed survey booklets, yielding a 14.4% response rate. To focus on the age cohort of our interest, we excluded respondents younger than 55 or older than 65. The final data includes 933 baby boomers from 745 households.

To represent relative traffic safety, we obtained motor vehicle crash data for three years (2006-2008) from the MassDOT Highway Division.[1] We successfully geocoded, using XY coordinates or addresses, approximately 82% of available crashes. The remaining records had inadequate location information. Spatial data, including building footprints and heights, roads, parcels, land use, and transportation systems, come from MassGIS.[2]

4.3. Measures and Descriptive Statistics

Table 1 presents variable definitions and descriptive statistics. Survey respondents reported the frequencies of *utilitarian* and *recreational* walking over the past week. The frequency of utilitarian walking is relatively evenly distributed. The distribution of recreational walking, on the other hand, is skewed, with 28% of individuals reporting zero recreational walking (hereafter we refer to these as "non-active"). Baby boomers in the sample are generally wealthy, healthy, and employed, with relatively high car and bike ownership rates. Our sample is biased towards wealthier households, although the gender composition is comparable to the estimated population of 55-65 year olds in the four cities studied.[3] The analysis includes the six psychological indicators, selected through exploratory factor analysis. From the indicators, confirmatory factor analysis identified two latent variables: *Safety Concern* regarding injury and crashes during walking, and *Supportive Social Norms* that encourage walking. This latent structure enters the SEM as a measurement model.[4]

We measured neighborhoods characteristics expected to influence baby boomers' walking behavior. Based on the assumption that only physical characteristics within a certain walking distance of the household location affect older adults' walking behavior, we defined "neighborhood" boundaries via 400 meter network buffers drawn according to walking paths along streets, rather than a buffer based on a straight line radius emanating from the household. The street network used is based on the roads data from MassGIS, excluding highways, since our focus is on pedestrians. We generated 400m network buffers for each household to represent the respective neighborhood (see Figure 2) and measured the physical characteristics and traffic crashes within each household's neighborhood.

Density: Typically measurements of density are population per acre and job per acre. However, these measures are coarse proxies of urban form. To approximate the intensity of activities, we utilized a net floor area ratio (FAR) measure that represents the amount of built activity space:

Net Density (FAR) = total floor area / total parcel area

Diversity: Following Rajamani (2003), we calculate a measure of the mix of local land uses relative to a perfect distribution of uses. We use six land uses in the calculation: residential, commercial, industrial, office, social/institutional, and leisure/recreational. Thus, the diversity index (DI) is expressed as:

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[1] http://www.mhd.state.ma.us/default.asp?pgid=content/traffic/crashrateeval&sid=about.
[2] http://www.mass.gov/mgis/massgis.htm.
[3] The Massachusetts Travel Survey, carried out in 2010-2011, indicates that in Boston, Brookline, Cambridge, and Somerville, 25% of 55 to 65 year olds live in households with more than $100,000 income, 30% with $50,000-$100,000, and 41% with less than $50,000 (approximately 5% did not respond to the income question). Approximately 42% in the age cohort of interest are male (MassDOT, 2012).
[4] In the interest of space, the exploratory and confirmatory analysis results are not presented. See the measurement models in Table 2a and 2b.

$$\text{DI} = 1 - \left\{ \frac{\left|\frac{r}{T} - \frac{1}{6}\right| + \left|\frac{c}{T} - \frac{1}{6}\right| + \left|\frac{i}{T} - \frac{1}{6}\right| + \left|\frac{n}{T} - \frac{1}{6}\right| + \left|\frac{p}{T} - \frac{1}{6}\right| + \left|\frac{l}{T} - \frac{1}{6}\right|}{\frac{5}{3}} \right\},$$

where r = area in residential use (single and multifamily housing); c = area in commercial use; i = area in industrial use; n = area in natural place; p = area in public/institutional use; l = area in leisure/recreational use; and the total area, $T = r + c + i + n + p + l$. A value of 0 for this index means that the land in the area has a single use and a value of 1 indicates perfect mixing among the six uses.

Design: A variety of neighborhood design elements may influence local behavior and perceptions of environmental quality. Open space, walking/biking paths, and street connectivity, measured by intersection density (Dill, 2004), may promote recreational and physical activities:

(1) *Open space density* = the area of open space / the area of the buffer,
(2) *Trail length* = the length of paths (km) within a buffer,
(3) *Intersection density* = the number of true intersections (three-way, four-way and more) / the area of the buffer (ha),

Topography, or specifically, hilliness, could influence both walk behavior (more energy required) and traffic safety (more dangerous terrain). We extract a measure from a digital elevation model:

Hilliness = the average slope (% rise),

Access to Potential Destinations: Gravity-based measurements estimate the accessibility of an origin to all potential destinations, assuming smaller and more distant opportunities exert smaller influences by incorporating time with a decay function. Our gravity-based walk accessibility combines land use (destinations) and transportation (distance) components:

Accessibility to Retail: $A_i = \sum_{i=1}^{J} [\exp(-b \cdot TT_{ij}) * 0.01],$

where i = origins (individual addresses); j = potential destinations; TT = walking time (minutes, based on network distance) from i to j; b = travel distance sensitivity parameter.

Access to Subway: We also estimate a gravity-based measure of walk accessibility to urban rail stations:

Accessibility to Transit: $AT_i = \sum_{i=1}^{T} [\exp(-b \cdot TT_{it})]$

Speed Limit: Higher average traffic speeds represent potentially higher traffic risk and greater pedestrian discomfort. We estimate average speeds based on the posted speed limits of roads within each network buffer.

AM Traffic Volume: AM Traffic Volume attempts to reflect exposure to traffic risk, which we define as the number of vehicle trips passing through a neighborhood during AM peak time (2 hours). The volumes come from the trip assignment stage of a 4-step transportation model calibrated for Boston.[5]

[5] We thank Vignesh Krishnamurthy for providing these model run estimates.

Traffic Crashes: To test effects of, and influences on, traffic safety, we use average annual traffic crash counts (averaged over 2006-2008) occurring within each 400m buffer (as geocoded from the available data). Figure 3a shows a kernel density map of all traffic crashes and Figure 3b shows those crashes involving pedestrians (as subset of all crashes). The pedestrian collision data reflect likely inconsistent reporting, across space, not surprising given the jurisdictional variation in reporting (across cities and across police jurisdictions within cities). This result is consistent with our own knowledge of traffic crash reporting in the area and confirmed by conversations with public health experts and city officials.[6] With more confidence in the consistency of reporting for motor vehicle crashes, we ultimately use these data to represent traffic safety. Figure 3a shows several hotspots along highways (I-93 and Storrow Drive), major roads (e.g., Massachusetts Avenue) and activity centers (e.g., Harvard Square, Central Square, and Coolidge Corner). This distribution foreshadows a positive association between traffic crashes and neighborhood characteristics.

4.4. Behavioral Modeling

As mentioned above, full structural equation modeling (SEM) enables us to estimate multiple effects among a large set of exogenous and endogenous variables, while consistently incorporating latent variables to control for self-selection. SEM can capture direct and indirect effects – the latter representing the product of effects on the two variables and the intervening variables. The total effect between the two variables is the sum of the direct and indirect effects (Golob, 2003). We use SEM – described with the path diagrams and equations in Figure 4 – to account for the complex relationships between exogenous variables (neighborhood and socio-economic characteristics,) and endogenous variables (traffic crashes, utilitarian walking, and recreational walking). We estimate two different models, for utilitarian and recreational walking, since these two walking behaviors have different motivations and may be sensitive in different ways to environmental and psychological conditions.

Our dependent variables, utilitarian walking and recreational walking, measure the reported count of respective weekly walk trips. The variables have different distributions, with recreational walking having a large share of zeros reported. For utilitarian walking we employ a negative binomial model, (Figure 4, Eq. 2), which relaxes the Poisson model's strict assumption that the mean should be equal to the variance of the dependent variable.[7] For recreational walking trips, the large share of zero-reported trips (28%; see Table 1) indicates censoring, such that ordinary count models may be inappropriate. Thus, we employ a zero-inflated model for recreational walking, combining a binary logit model to estimate the likelihood of being in non-active (*zero* walking) and active groups and a count model, which weights the zeros based on the likelihood of being active/non-active as estimated in the logit model (Figure 4, Eqs. 1–3).[8] The zero-inflated model yields two sets of coefficients. The logit model estimates the effect of each variable on the probability of being in the non-active group; negative coefficients indicate a higher probability of being in the active group. The count model estimates the effect of each variable on trip frequency; positive coefficients imply a higher frequency of recreational walking.

The count models are incorporated with measurement and structural equations in the SEM that controls for self-selection, simultaneously incorporating latent variables. The SEM estimates the latent

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[6] The pedestrian-vehicle collision data from MassDOT apparently under-report crashes involving pedestrians in Boston. As a consequence, the pedestrian-vehicle crash rate in Cambridge is much higher than in Boston (see Figure 2b), which is unlikely considering downtown Boston's high levels of vehicular and pedestrian movements.

[7] The likelihood ratio test indicates that a negative binomial model is preferable to a Poisson model.

[8] These logit probabilities weight the zeros in the count model such that the probability of observing zero for an individual equals the probability of being non-active plus the probability of being active, multiplied by the probability of observing zero in the count model (Jones, 2005).

variables – extracted from the indicators in the measurement model (Figure 4, Eq. 6) – conditional upon socio-economic characteristics and traffic crashes (Figure 4, Eq. 4). The model also includes effects of neighborhood characteristics on the traffic crash level (Figure 4, Eq. 5). Thus, walking behavior, traffic crashes, and latent variables are endogenous, while socio-economic status and neighborhood physical characteristics are exogenous. These models are estimated in Mplus 5.0, using maximum a likelihood estimator with robust standard errors that are robust to non-normality and adjusted to account for non-independence of observations (i.e., respondents from the same household) (Muthen & Muthen, 2004, 2007).[9]

5. RESULTS

5.1. Utilitarian Walking

Table 2a presents the utilitarian walking model results and Figure 5a displays the significant effects. The results confirm the spatial pattern of traffic crashes in Figure 3a and our first hypothesis that neighborhood characteristics are correlated with the number of traffic crashes. Accessibility to retail shops, as well as speed limit and AM traffic volume, are associated with a larger number of traffic crashes. Neighborhoods with high intersection density, open space density, and hilliness tend to yield fewer traffic crashes, implying lower vehicle volume/speed or cautious driving in such areas. These neighborhood characteristics indirectly affect utilitarian walking via effects on traffic safety.

The results also support our second hypothesis regarding the negative effect of traffic crashes, as well as the direct effects of neighborhood characteristics on utilitarian walking. The average traffic crashes in a neighborhood significantly discourage older adults' walking. Neighborhood characteristics, such as land use diversity, intersection density, and accessibility to retail are significantly associated with higher utilitarian walking frequency. Speed limit is positively correlated with walking levels, a surprising result, possibly implying that utilitarian walking activities in a neighborhood are encouraged by major roads.

The direct, indirect, and total effects of neighborhood characteristics are presented in Table 3a. Better accessibility to retail and a higher share of major roads, represented by speed limit, indirectly discourage older adults' utilitarian walking through traffic safety effects, although they directly encourage walking. Among personal characteristics, baby boomers with disabilities or car owners are less likely to walk. The model also identified significant influences of psychological factors: Individuals with higher level of safety concerns tend to walk less, while an individual's sense of having social norms that support walking significantly encourages utilitarian walking.

5.2. Recreational Walking

We estimate a zero-inflated negative binomial (ZINB)[10] model for recreational walk trips, estimating first the likelihood of being in the non-active group and then the number of recreational walk trips among the active group (Table 2b and Figure 5b). The result indicates that higher traffic crash levels increase the likelihood of being in the non-active group. However, supportive social norms encourage baby boomers to be "active" (make at least one recreational walk trip per week). Neighborhood characteristics, net FAR and land use diversity are positively correlated with recreational walking frequency. Regarding

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[9] Our dataset contains a clustering structure: some individuals are nested in households. Thus, it is necessary to account for potential correlation of behavior among same-household individuals (i.e., intra-class correlation), which may influence standard errors in the model results. We use "cluster" option in Mplus that corrects standard errors.

[10] The Vuong test indicates that ZINB is superior to a negative binomial, and a likelihood ratio test indicates ZINB is preferable to a zero-inflated Poisson

individuals, employed baby boomers tend to walk less, while dog owners are likely to walk for recreation more frequently. The model also detects indirect effects of accessibility to retail, traffic speed, and volume that discourages individuals to be in the active walking group.

5.3. Implications

Our models reveal the more complex inter-relationships between urban form, traffic safety and active travel for urban-dwelling older adults. "Walkable" neighborhoods, particularly those with good accessibility to retail, are correlated with more traffic crashes (and higher pedestrian risks), effects which indirectly discourage utilitarian and recreational walking. These countervailing effects are consistent with those discussed in previous studies (Miranda-Moreno et al., 2011; Moudon et al., 2011). The findings also suggest the need for examining more closely the causality implied in the "safety in numbers" argument (i.e., a larger number of pedestrians leads to improved safety levels). Our utilitarian walk model shows that higher traffic crash frequency decreases older adults' walking. In other words, older adults are likely to participate in more walking activities in safer neighborhoods, implying a potential "numbers in safety" argument. Nonetheless, this result should be viewed tentatively, as we do not have reliable traffic and pedestrian volume data.

The effect of social norms on utilitarian and recreational walking is consistent with previous findings that social support is associated with physical activity, particularly among older adults (Bauman & Bull, 2007). The result indicates that older adults' perceptions about neighborhood safety play a significant role in engaging in walking activity. That is, both physical and non-physical (e.g., social support for walking) interventions can contribute to increased activity levels of older adults. Nonetheless, despite the significant influence of latent variables, we find little evidence of self-selection for utilitarian walking: the latent variables are not conditional upon safety from traffic, and the inclusion of latent variables does not discernibly change the signs, magnitudes, or significance levels of traffic crashes and other neighborhood characteristics.[11] This result is inconsistent with previous findings about the complex relationships between actual and perceived safety. Cho et al. (2009) find that a higher actual risk of traffic collisions increases perceived risk. However, higher perceived risk is, in turn, negatively correlated with actual risk: people tend to perceive mixed use areas with higher traffic crash rates as safer than single use neighborhoods due to lower expectation of injury severity (Cho et al., 2009; Schneider et al., 2004). We can identify several causes for our finding an insignificant association between actual traffic crashes and safety concern in our study. It may simply be the actual relationship in this particular context for this particular cohort. We should not, however, ignore data and study design causes. For example, our analysis still encompasses relatively homogeneous built urban environments, while previous studies examined urban and suburban neighborhoods. Also, as discussed previously, our traffic crash and exposure data are likely inaccurate.

5.4. Shortcomings and Future Research

As just mentioned, our analysis suffers from data quality issues. First, our results only apply directly to a specific demographic, geography and time of year (i.e. October, 2010) and may not be generalizable. For example, based on other evidence, it appears our sample is biased towards higher income households. Even for the specific groups and areas studied, our sampling procedure likely suffers from other unknown biases that further limit validity and generalizability. In terms of contextual data, the traffic crash data are certainly inaccurate, as discussed, and using total traffic crashes, instead of pedestrian-vehicle collisions

[11] The model results without latent variables are not included; full results are available upon request.

may be problematic. More systematic, consistent data collection and validation procedures are necessary. In addition, our data do not include numerous potentially relevant micro-scale built environment measures, such as sidewalk conditions, roadway design, street crossing design, and traffic calming devices, which may influence pedestrian safety (Ewing & Dumbaugh, 2009; Zegeer et al., 2005). These omitted variables may be confounding our results (Bhatia & Wier, 2011), warranting further investigation.

Analytically, despite the application of full SEM to strengthen causal inference, the cross-sectional, observational study design cannot overcome the fundamental limitation: being unable to capture behavioral changes corresponding to changing environments. Such analysis would require an experimental design with longitudinal data. The increased modeling sophistication of SEM comes at a cost as our particular SEM cannot easily reveal relative or marginal effects, only significance and directionality. Another analytical shortcoming is the inability to account for spatial dependency among individual observations. The spatial distributions of traffic crashes and behavioral outcomes suggest the existence of spatial autocorrelation, which can produce potential bias in the models. We do not account for potential spatial dependency, due to the difficulty in combining SEM and spatial models, another area for future research.

6. CONCLUSIONS

The study sheds light on the countervailing effects of walkable urban environments on older adults' walking activities, analyzing behavioral data (utilitarian and recreational walking) from a mail-back survey and using objective built environment and traffic safety measures. Our models find that walkable urban forms (mixed use, well-connected streets, and good access to potential destinations) directly encourage older adults' walking, but that higher traffic speed/volume and accessibility to retail are associated with frequent traffic crashes that, in turn, discourage walking.

The results suggest more cautious approaches may be necessary for designing urban spaces for walkability and also call into question prescriptions based on the "safety in numbers" hypothesis. Even if high crash rates do not mean higher risk per person as the safety in numbers would suggest, the absolute number of crashes is still high in walkable activity centers. Frequent crashes can lead older adults to hesitate to walk. Thus, the goal of planning or policy should minimize both the rate and absolute number of collisions, considering older adults' vulnerability to traffic crashes. If walkable neighborhood-scale planning and design interventions that seek to improve walkability can unintentionally increase overall exposure to traffic hazard, other actions should be considered to enhance pedestrian safety. Micro-scale designs (e.g., better crossing design and countermeasures) and speed regulations at activity centers (hot spots of crashes) may be promising approaches to complement neighborhood-level planning strategies, improving walkability and pedestrian safety simultaneously.

Psychological latent factors, although providing little evidence of self-selection in our case, do apparently influence older adults' walking: supportive socials norms encourage utilitarian walking and safety concerns reduce recreational walking. These findings suggest that educational or social programs to promote safe walking may coax older adults to engage in additional walking activities. Physical interventions that assure pedestrian safety and reduce anxiety about walking may also be effective. Overall, the study improves understanding of the complex relationships among the built environment, safety, and psychological characteristics that, together, influence baby boomers' walking behavior.

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Table 1. Definitions and Descriptive Statistics of Variables (N= 914)

Variables		**Mean**	**SD**	**Min**	**Max**
<u>*Endogenous Variables*</u>					
Utilitarian Walking	During the past seven days, how many times did you walk for going to work, shopping, eating, errand, etc?	6.99	5.12	0	24
Recreational Walking	During the past seven days, how many times did you walk for exercise or a stroll in your neighborhood	3.49	3.60	0	12
	Ratio of individuals reporting *zero* recreational walking over past week (i.e., "non-active)	0.28*	-	-	-
Traffic Collisions	Average of the total numbers of traffic collisions recorded in 2006, 2007, and 2008	30.60	21.30	0.00	119.0
<u>*Neighborhood Characteristics*</u>					
Net FAR	Net floor-area-ratio	2.92	1.68	0.95	15.30
Land Use Diversity	Land use diversity index	0.29	0.13	0.00	0.74
Intersection Density	True intersection density (True intersections / ha)	1.55	0.49	0.00	3.53
Open Space Density	Percentage of open space	6.07	6.87	0.00	58.20
Trail Length	Total street length of trails and walking paths (km)	0.07	0.16	0.00	1.07
Hilliness	Percentage increase	1.19	1.10	0.00	7.52
Accessibility to Retail	Gravity-based accessibility to retail shops	0.10	0.13	0.00	1.35
Accessibility to Transit	Gravity-based accessibility to T-stations (Subway)	0.07	0.19	0.00	1.56
Speed Limit	Average speed limit of roads (km/h)	32.30	4.55	23.60	49.90
AM Traffic Volume	Estimated AM Traffic Volume (1000 vehicles / 3 hours)	31.46	20.43	0.30	116.4
<u>*Socio-Economic Characteristics*</u>					
High-Income	HH income (> $100k) (0. Otherwise, 1. High)	0.42	-	0	1
Mid-Income	HH income ($50k- 99.9k) (0. Otherwise, 1. Medium)	0.41	-	0	1
Low-Income (base)	HH income (< 49.9k) (0. Otherwise, 1. Low)	0.17	-	0	1
Disability	Health status (0. Unhealthy, 1. Healthy)	0.06	-	0	1
Employ	Employment status (0. Unemployed, 1. Employed)	0.68	-	0	1
Male	Gender (0. Female, 1. Male)	0.41	-	0	1
Own a Dog	Dog in a household (0. None, 1. More than one dogs)	0.12	-	0	1
Own a Bike	Bikes in a household (0. None, 1. More than one bikes)	0.53	-	0	1
Own a Car	Cars in a household (0. None, 1. More than one cars)	0.79	-	0	1
<u>*Psychological Indicators (Five-point Likert Scale)*</u>					
Utilitarian Risk	For me, the experience of walking to get to shopping or errands would overall be: (safe: 1 2 3 4 5 :unsafe)	4.54	0.81	1	5
Recreational Risk	For me, the experience of walking to get to shopping or errands would overall be: (safe: 1 2 3 4 5 :unsafe)	4.50	0.82	1	5
Injury Concern	If I wanted to walk, I am unlikely to do it because I am concerned about falling or injuring myself.	1.42	0.93	1	5
Collision Concern	If I wanted to walk, I am unlikely to do it because I am concerned about being in a collision with cars.	1.37	0.81	1	5
Should Walk	Most people who are important to me think that I should walk.	4.10	1.17	1	5
Support Walking	Most people who are important to me would support me if I chose to walk rather than to drive.	4.42	0.94	1	5

Note: *: 253 individuals reported *zero* recreational walking; - : indicates not applicable.

Table 2a. Utilitarian Walking Model Results (N = 914)

	Negative Binomial Model		Structural (MIMIC) Model & Measurement Model					
	Number of Utilitarian Walking		*Traffic Collision*		*Safety Concern*		*Supportive Social Norms*	
	Coeff.	**(S.E.)**	**Coeff.**	**(S.E.)**	**Coeff.**	**(S.E.)**	**Coeff.**	**(S.E.)**
Endogenous Variables								
Traffic Collisions	-0.004*	(0.002)	-	-	-	-	-	-
Safety Concern	-0.131**	(0.049)	-	-	-	-	-	-
Supportive Social Norms	0.109*	(0.043)	-	-	-	-	-	-
Exogenous Variables								
Net FAR	0.010	(0.021)	0.021	(0.987)	-	-	-	-
Land Use Diversity	0.737**	(0.241)	-5.480	(5.384)	-	-	-	-
Intersection Density	0.115*	(0.057)	-4.180**	(1.557)	-	-	-	-
Open Space Density	-0.005	(0.005)	-0.514**	(0.109)	-	-	-	-
Trail Length	-0.069	(0.155)	7.102	(5.660)	-	-	-	-
Hilliness	-0.042	(0.030)	-2.594**	(0.746)	-	-	-	-
Accessibility to Retail	0.737*	(0.289)	21.129*	(9.320)	-	-	-	-
Accessibility to Transit	0.174	(0.136)	0.831	(3.565)	-	-	-	-
Speed Limit	0.024**	(0.008)	0.666**	(0.196)	-	-	-	-
AM Traffic Volume	0.001	(0.002)	0.570**	(0.040)	-	-	-	-
High-Income	-0.153†	(0.085)	-	-	-0.426**	(0.113)	0.311†	(0.180)
Mid-Income	-0.082	(0.075)	-	-	-0.231*	(0.112)	0.198†	(0.119)
Disability	-0.445**	(0.151)	-	-	0.586**	(0.183)	-0.177	(0.212)
Employ	-0.004	(0.053)	-	-	-0.022	(0.066)	-0.052	(0.092)
Male	0.010	(0.049)	-	-	-0.076	(0.054)	-0.081	(0.100)
Own a Dog	0.145†	(0.082)	-	-	-0.055	(0.071)	-0.082	(0.090)
Own a Bike	0.084	(0.053)	-	-	-0.069	(0.067)	0.077	(0.074)
Own a Car	-0.182**	(0.060)	-	-	0.020	(0.090)	-0.005	(0.085)
Dispersion	0.379**	(0.033)	-	-	-	-	-	-
Psychological Indicators								
I_1: Injury Concern	-	-	-	-	1.000	(0.000)	-	-
I_2: Collision Concern	-	-	-	-	0.796**	(0.111)	-	-
I_3: Recreational Risk	-	-	-	-	0.420**	(0.099)	-	-
I_4: Should Walk	-	-	-	-	-	-	1.000	(0.000)
I_5: Support Walking	-	-	-	-	-	-	1.088*	(0.508)

Note: † p<0.10, * p<0.05, ** p<0.01; The model is over identified with 66 free parameters and 25 observed variables (66 < 0.5*25*(25+1)).

Table 2b. Recreational Walking Model Results (N = 914)

	Zero-Inflated Negative Binomial Model				**Structural (MIMIC) Model & Measurement Model**					
	Likelihood of being in Non-active group		*Number of Recreational Walking*		*Traffic Collision*		*Safety Concern*		*Supportive Social Norms*	
	Coeff.	**(S.E.)**	**Coeff.**	**(S.E.)**	**Coeff.**	**(S.E.)**	**Coeff.**	**(S.E.)**	**Coeff.**	**(S.E.)**
Endogenous Variables										
Traffic Collisions	0.018*	(0.007)	0.001	(0.002)	-	-	-	-	-	-
Safety Concern	0.323†	(0.171)	0.040	(0.059)	-	-	-	-	-	-
Supportive Social Norms	-0.419**	(0.134)	0.051	(0.037)	-	-	-	-	-	-
Exogenous Variables										
Net FAR	0.062	(0.083)	0.068**	(0.021)	0.021	(0.987)	-	-	-	-
Land Use Diversity	0.364	(1.077)	1.087**	(0.289)	-5.480	(5.384)	-	-	-	-
Intersection Density	-0.492†	(0.279)	-0.007	(0.071)	-4.180**	(1.557)	-	-	-	-
Open Space Density	-0.009	(0.017)	0.008†	(0.005)	-0.514**	(0.109)	-	-	-	-
Trail Length	-0.260	(0.720)	-0.161	(0.209)	7.102	(5.660)	-	-	-	-
Hilliness	0.008	(0.114)	-0.048	(0.033)	-2.594**	(0.746)	-	-	-	-
Accessibility to Retail	-1.516	(2.165)	-0.324	(0.392)	21.129*	(9.320)	-	-	-	-
Accessibility to Transit	-1.710*	(0.794)	0.090	(0.152)	0.831	(3.565)	-	-	-	-
Speed Limit	-0.030	(0.033)	0.002	(0.010)	0.666**	(0.196)	-	-	-	-
AM Traffic Volume	-0.011	(0.009)	-0.005*	(0.002)	0.570**	(0.040)	-	-	-	-
High-Income	0.030	(0.376)	0.078	(0.102)	-	-	-0.444**	(0.114)	0.403**	(0.140)
Mid-Income	-0.094	(0.326)	0.037	(0.096)	-	-	-0.244*	(0.114)	0.219	(0.139)
Disability	0.540	(0.428)	-0.286†	(0.157)	-	-	0.585**	(0.184)	-0.272	(0.220)
Employ	0.294	(0.229)	-0.221**	(0.067)	-	-	-0.027	(0.067)	-0.109	(0.093)
Male	0.187	(0.218)	0.017	(0.062)	-	-	-0.087	(0.056)	-0.165*	(0.081)
Own a Dog	-0.354	(0.342)	0.580**	(0.083)	-	-	-0.054	(0.073)	-0.082	(0.119)
Own a Bike	-0.062	(0.236)	0.026	(0.068)	-	-	-0.063	(0.068)	-0.008	(0.121)
Own a Car	-0.261	(0.264)	-0.151†	(0.088)	-	-	0.019	(0.092)	0.038	(0.116)
Dispersion	-	-	0.314**	(0.037)	-	-	-	-	-	-
Psychological Indicators										
I_1: Injury Concern	-	-	-	-	-	-	1.000	(0.000)	-	-
I_2: Crash Concern	-	-	-	-	-	-	0.769**	(0.110)	-	-
I_3: Recreational Risk	-	-	-	-	-	-	0.355**	(0.097)	-	-
I_4: Should Walk	-	-	-	-	-	-	-	-	1.000	(0.000)
I_5: Support Walking	-	-	-	-	-	-	-	-	0.590**	(0.187)

Note: † p<0.10, * p<0.05, ** p<0.01; The model is over identified with 88 free parameters and 24 observed variables (88 < 0.5*25*(25+1)).

Table 3a. Direct, Indirect, and Total Effects of Urban Form Measures on the Utilitarian Walking Frequency

	Effect on Traffic Collision	***Effect on the Utilitarian Walking Frequency***		
		Indirect Effect	***Direct Effect***	***Total Effect***
Net FAR	-	-	-	-
Land Use Diversity	-	-	0.737	0.737
Intersection Density	-4.180	(-4.180) * (-0.004) = 0.017	0.115	0.132
Open Space Density	-0.514	(-0.514) * (-0.004) = 0.002	-	0.002
Trail Length	-	-	-	-
Hilliness	-2.594	(-2.594) * (-0.004) = 0.010	-	0.010
Accessibility to Retail	21.129	(21.129) * (-0.004) = -0.085	0.737	0.652
Accessibility to Transit	-	-	-	-
Speed Limit	0.666	(0.666) * (-0.004) = -0.003	0.024	0.021
AM Traffic Volume	0.570	(0.570) * (-0.004) = -0.002	-	-0.002

Table 3b. Direct, Indirect, and Total Effects of Urban Form Measures on the Likelihood of Being in Non-active Recreational Walking Group

	Effect on Traffic Collisions	***Effect on the Likelihood of Being in Non-active Recreational Walking Group***		
		Indirect Effect	***Direct Effect***	***Total Effect***
Net FAR	-	-	-	-
Land Use Diversity	-	-	-	-
Intersection Density	-4.180	(-4.180) * (0.018) = -0.075	-	-0.075
Open Space Density	-0.514	(-0.514) * (0.018) = -0.009	-	-0.009
Trail Length	-	-	-	0.000
Hilliness	-2.594	(-2.594) * (0.018) = -0.047	-	-0.047
Accessibility to Retail	21.129	(21.129) * (0.018) = 0.380	-	0.380
Accessibility to Transit	-	-	-1.710	-1.710
Speed Limit	0.666	(0.666) * (0.018) = 0.012	-	0.012
AM Traffic Volume	0.570	(0.570) * (0.018) = 0.010	-	0.010

Figure 1. Conceptual Framework: Older Adults Walking Behavior and the Role of Urban Form and Traffic Safety

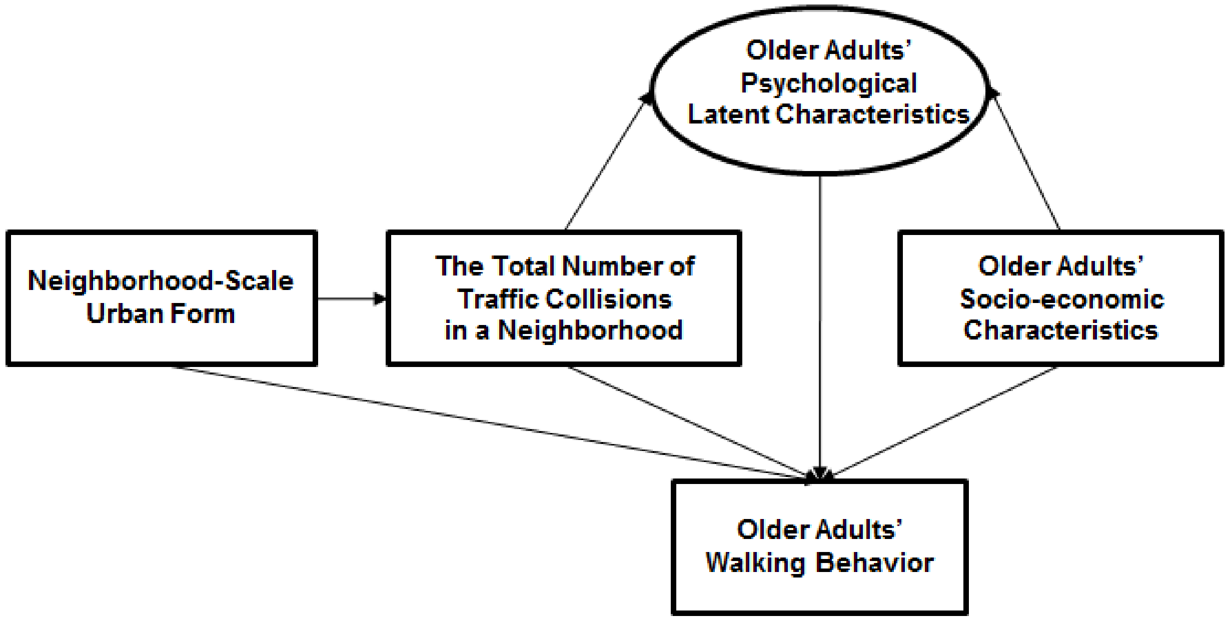
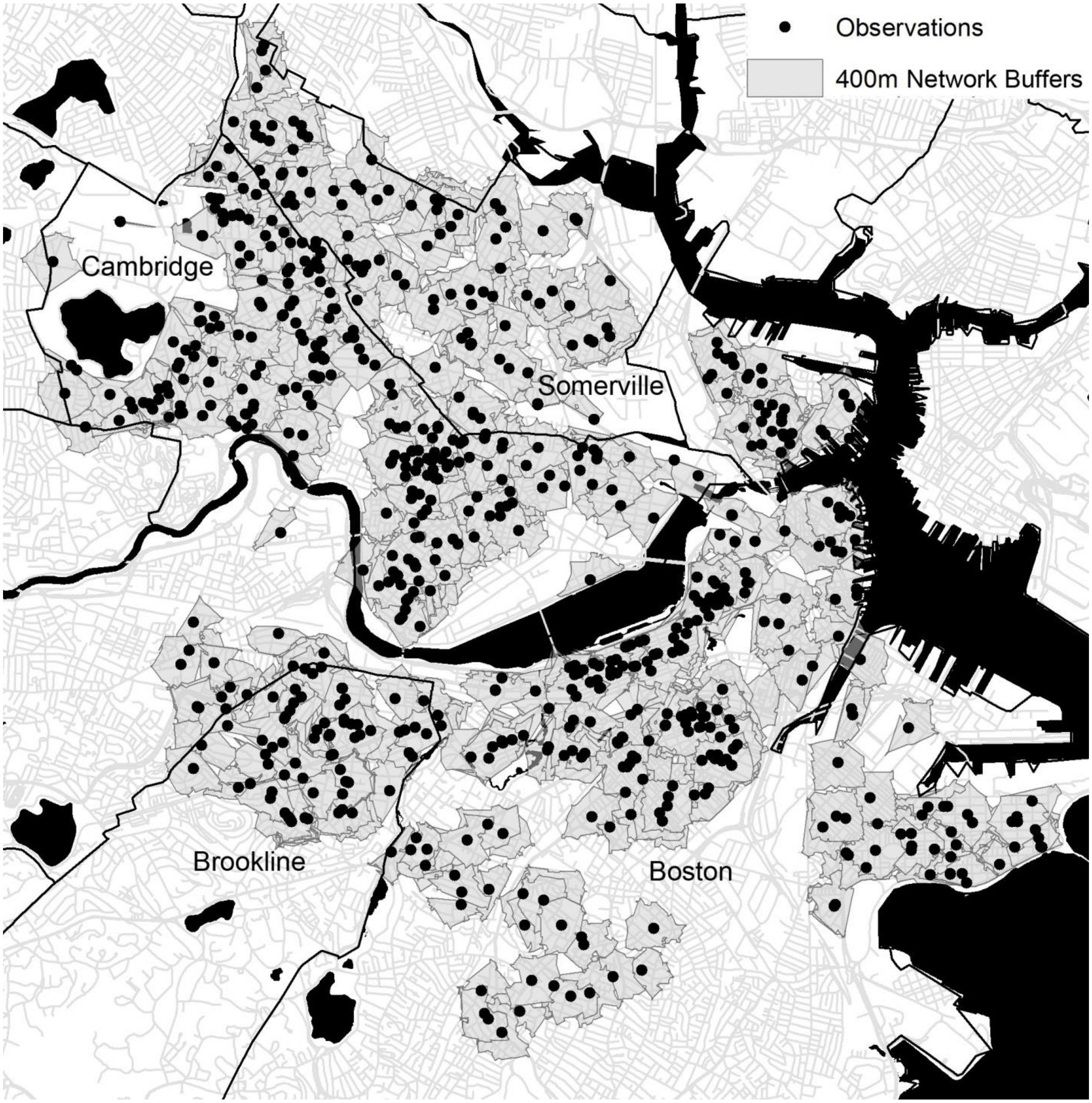
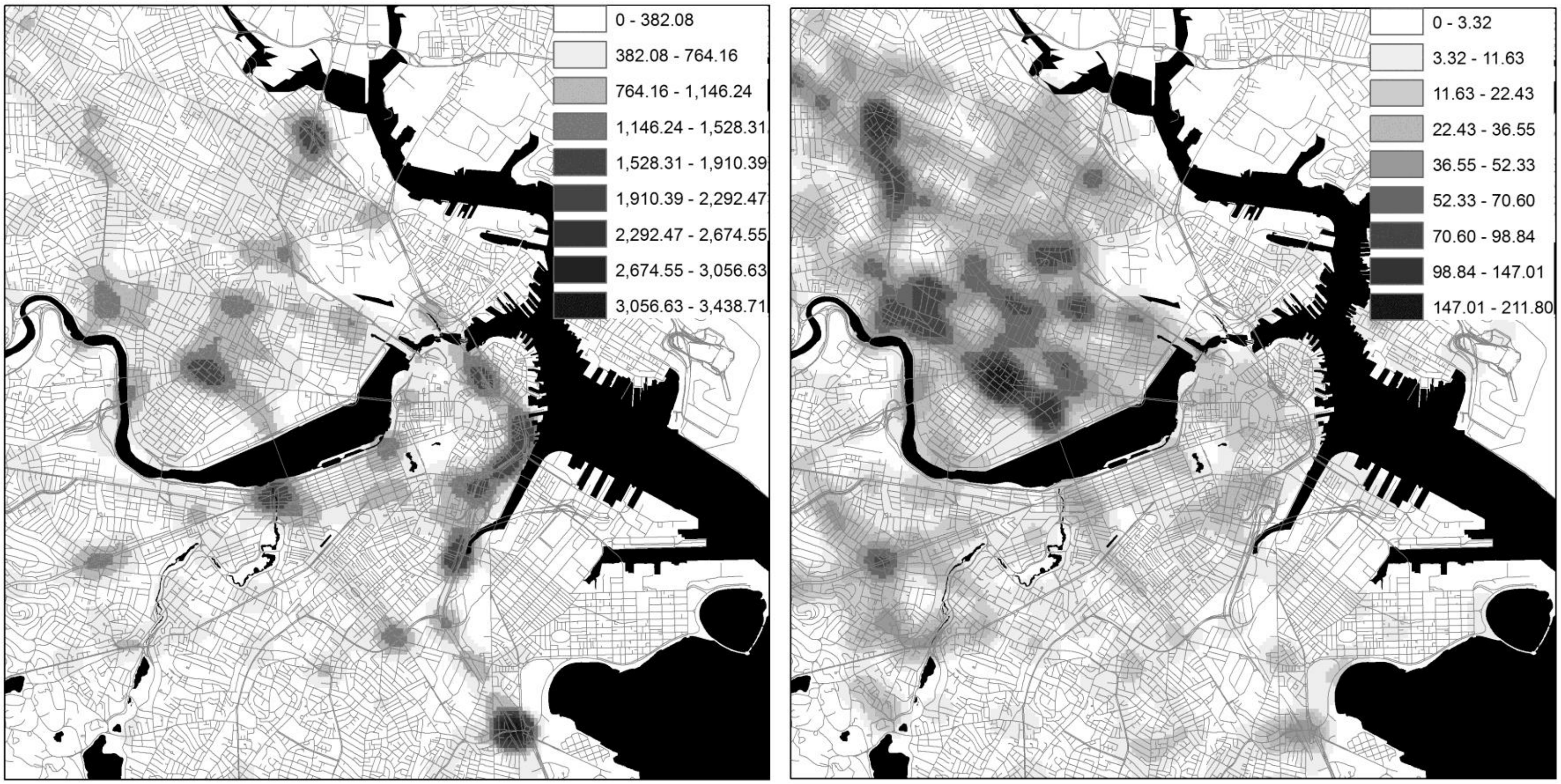


Figure 2. 400m Walk Network Buffers based on the Geocoded Addresses of Respondents

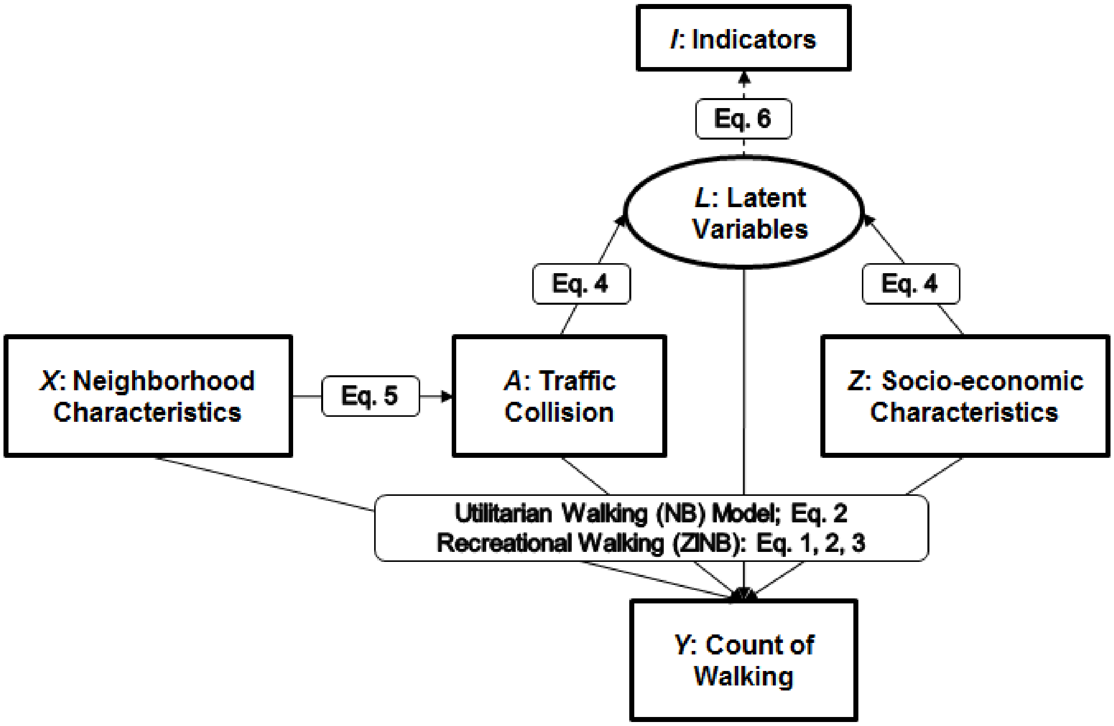




(a) Total Traffic Collisions **(b) Pedestrian-Vehicle Collisions**

Figure 3. Kernel Density Maps of Total Traffic Collisions (Left) and Pedestrian-Vehicle Collisions (Right).

Figure 4. Path Diagrams and Equations of Structural Equation Models Estimating Relationships among the Built Environment, Traffic Safety, and Travel Behavior



Zero-Inflated Negative Binomial (ZINB) Model

Logit Model: (Eq. 1)

$\text{Logit}(\mu=0) = X\beta+Z\gamma+L\rho+\varepsilon$

$P(y_i = 0) = \pi = \frac{1}{e^{-(X\beta+Z\gamma+L\rho)}},\ \ y_i = 0, 1, 2, 3, \dots$

Negative Binomial Model (NB): (Eq. 2)

$\ln Y = X_{nb}\beta_{nb}+Z_{nb}\gamma_{nb}+L_{nb}\rho_{nb}+\zeta$

$P(y_i|x_{nb,i}, z_{nb,i}, l_{nb,i}) = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!},\ \ y_i = 0, 1, 2, 3, \dots$

$E(y_i|x_{nb,i}, z_{nb,i}, l_{nb,i}) = \mu_i = e^{(X_{nb}\beta_{nb}+Z_{nb}\gamma_{nb}+Y_{nb}\rho_{nb})}$

$V(y_i|x_{nb,i}, z_{nb,i}, l_{nb,i}) = \mu_i(1+\alpha\mu_i)$

Combining the logit and NB models: (Eq. 3)

$P(y_i|x_i, z_i, y_i, x_{nb,i}, z_{nb,i}, y_{nb,i})$

$= \begin{cases} \pi + (1-\pi)\,P(0|x_{nb,i}, z_{nb,i}), & \text{if } y_i = 0 \\ (1-\pi)\,P(y_i|x_{nb,i}, z_{nb,i}), & \text{if } y_i > 0 \end{cases}$

X	Neighborhood Characteristics
Z	Socio-economic Characteristics
L	Latent Variables
Y	Count of Walking
μ	Expected count
π	Probability of being in zero-count group
α	Variance (Dispersion) parameter
β, γ, ρ	Unknown parameters
ε, ζ	Random disturbance terms

Structural Equation Model (SEM)

Structural Model (Eq. 4)

$L = Z\eta + A\omega + \xi,\ \ \xi \sim N(0, \psi_\xi\ diagonal)$

Structural Model (Eq. 5)

$A = X\theta + \kappa,\ \ \kappa \sim N(0, \iota_\kappa\ diagonal)$

Measurement Model (Eq. 6)

$I = L\lambda + \delta,\ \ \delta \sim N(0, \varphi_\delta\ diagonal)$

A	Traffic Collision
X	Neighborhood Characteristics
Z	Socio-economic Characteristics
L	Latent Variables
I	Indicators of L
$\eta, \omega, \theta, \lambda$	Unknown parameters
ξ, κ, δ	Random disturbance term
ψ, ι, φ	Covariances of random disturbance term

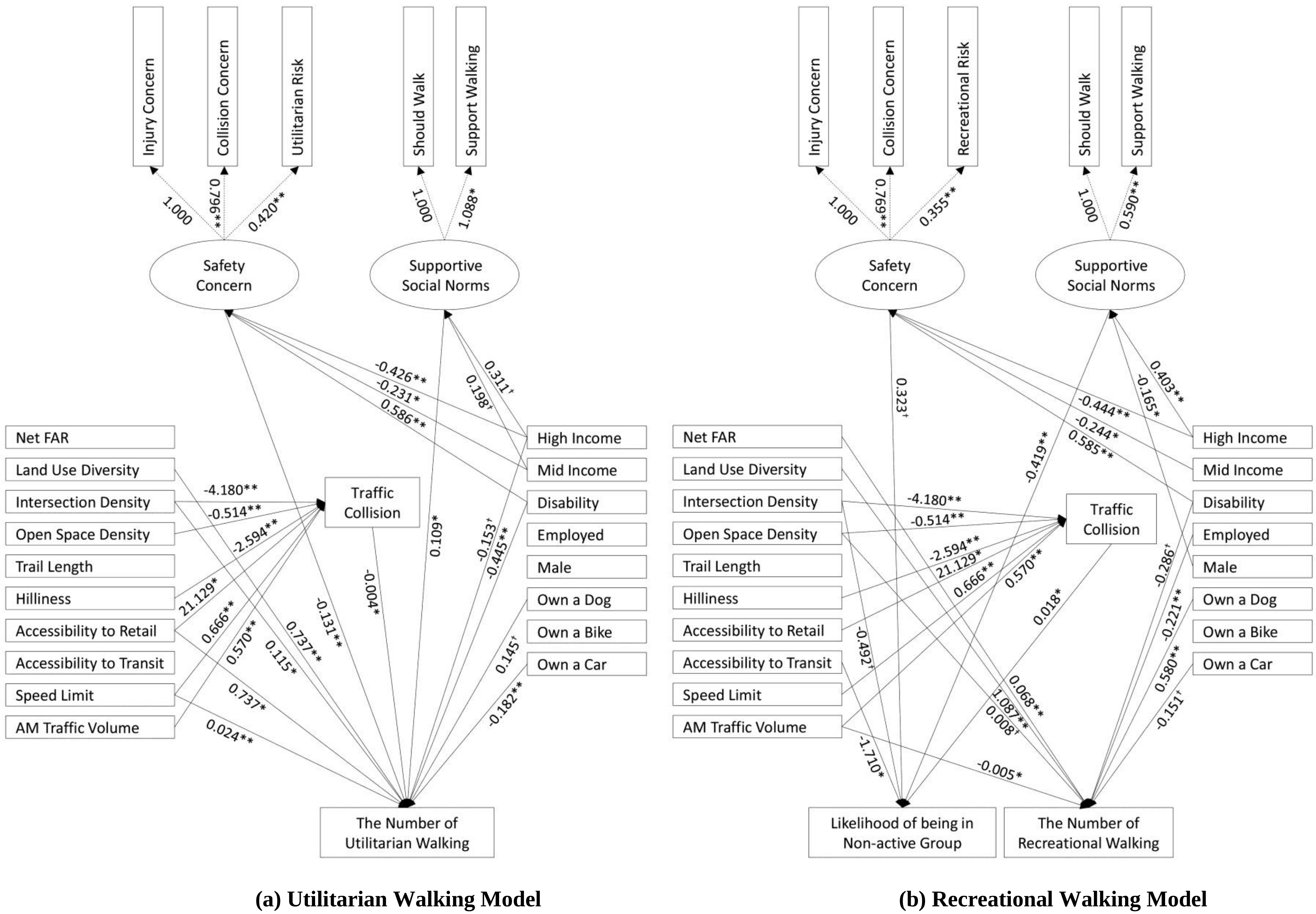


Figure 5. Path Diagram and Results of Utilitarian Walking (Left) and Recreational Walking (Right) Models
Note: Results from Models in Tables 2.1, 2.2; † p<0.10, * p<0.05, ** p<0.01