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Modeling spatial segregation and travel cost influences on utilitarian walking: Towards policy intervention

Yong Yang [a,*], Amy H. Auchincloss [b], Daniel A. Rodriguez [c], Daniel G. Brown [d], Rick Riolo [e], Ana V. Diez-Roux [f]

[a] School of Public Health, University of Memphis, Memphis, TN, USA
[b] Department of Epidemiology and Biostatistics, Drexel University, Philadelphia, PA, USA
[c] Department of City and Regional Planning, University of North Carolina, Chapel Hill, NC, USA
[d] School of Natural Resources & Environment, University of Michigan, Ann Arbor, MI, USA
[e] Center for the Study of Complex Systems, University of Michigan, Ann Arbor, MI, USA
[f] School of Public Health, Drexel University, Philadelphia, PA, USA

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ABSTRACT

We develop an agent-based model of utilitarian walking and use the model to explore spatial and socioeconomic factors affecting adult utilitarian walking and how travel costs as well as various educational interventions aimed at changing attitudes can alter the prevalence of walking and income differentials in walking. The model is validated against US national data. We contrast realistic and extreme parameter values in our model and test effects of changing these parameters across various segregation and pricing scenarios while allowing for interactions between travel choice and place and for behavioral feedbacks. Results suggest that in addition to income differences in the perceived cost of time, the concentration of mixed land use (differential density of residences and businesses) are important determinants of income differences in walking (high income walk less), whereas safety from crime and income segregation on their own do not have large influences on income differences in walking. We also show the difficulty in altering walking behaviors for higher income groups who are insensitive to price and how adding to the cost of driving could increase the income differential in walking particularly in the context of segregation by income and land use. We show that strategies to decrease positive attitudes towards driving can interact synergistically with shifting cost structures to favor walking in increasing the percent of walking trips. Agent-based models, with their ability to capture dynamic processes and incorporate empirical data, are powerful tools to explore the influence on health behavior from multiple factors and test policy interventions.

1. Introduction

Walking for transportation is a feasible way to incorporate regular physical activity into daily life. Regular physical activity is important for maintaining a healthy weight and can reduce the risk for many chronic diseases (Department of Health and Services, 2008; Powell, Paluch, & Blair, 2011). However, only 6% of US adults routinely engage in walking for transportation (⩾5 days/week for -⩾ 30 min/day) and only about 18% of all trips in the US are made via walking (Pucher, Buehler, Merom, & Bauman, 2011).

Americans primarily rely on private automobiles for transportation, which has enabled low-density development and contributed to poor air quality (Frumkin, Frank, & Jackson, 2004; Marshall, McKone, Deakin, & Nazaroff, 2005). At the same time, low-density urban development has encouraged further reliance on automobiles for mobility and has heightened the challenges of providing high-quality public transportation services. Inappropriate price signals are frequently invoked as a factor that skews travel toward the automobile and away from walking and public transit. For example, in the US, the cost of gasoline has declined since 1980 (after accounting for inflation and gains in fuel efficiency) and free, convenient parking is plentiful around residences, worksites, shopping and leisure destination (Auchincloss, Weinberger, Aytur, Namba, & Ricchezza, 2014; Shoup, 1997, 2011). To date, the majority of work on transportation prices has focused on how it can reduce auto use or increase transit use (Guo, 2013; Marsden, 2006; Salon, Boarnet, Handy, Spears, & Tal, 2012). Despite the importance of prices for people's travel choices, there is limited research examining how pricing automobile use can also have an impact on walking behaviors (Courtemanche, 2011; Hou et al.,

* Corresponding author at: School of Public Health, University of Memphis, Memphis, TN 38111, USA.
E-mail address: yangyong712@hotmail.com (Y. Yang).

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2011). For example, one recent review (Martin, Suhrcke, & Ogilvie, 2012) claimed that financial incentives may have a larger role in promoting walking and cycling than is acknowledged generally although the conclusion was based on evidence predominantly involving free bicycles or local road pricing at specific locations and for specific groups.

It is well established that many health behaviors vary across socioeconomic groups. Walking for transportation is an atypical example in that, in contrast to many other behaviors, lower income groups tend to engage in healthier behaviors (i.e. walk more) than higher income groups (Kruger, Ham, Berrigan, & Ballard-Barbash, 2008; Pucher & Renne, 2003). This is due in part to difficulties faced by low income households in assuming the costs of automobile ownership, operation, and maintenance. Compared to high income households, the well-being of lower income households has a higher dependence on proximity to health-promoting services, safe walking environments, and quality of public transit. Residential segregation by household income, a common feature of older post-industrial cities in the US, also has implications for walking behavior and differences in walking by income. In many older US cities, lower-income households tend to be located in or around the center of the city, while higher-income households locate on the city's outskirts. Density of residential and commercial land use also tend to be spatially patterned (Anas, Arnott, & Small, 1998). Spatially patterned proximity to destinations may also exert an important influence on walking behavior and income differences in walking behavior. Thus, in evaluating the impact of various policies (including pricing) on walking behavior it is important to evaluate their impact on income differences in walking in the context of various spatial segregation scenarios.

A major challenge in investigating the impact of various policies on walking behavior and its income differences at the population level is the need to account for the dynamic relationships among individuals (e.g. the behavior of one individual affecting others), between individuals and their built and social environments (e.g. the environment changing in response to the behaviors of individuals and vice versa), and among environmental characteristics (Cerin, Leslie, & Owen, 2009). However, data are often unavailable for examining these dynamic interactions and the interactions cannot be easily captured using traditional statistical methods. Agent-based models (ABM) are computational models that can be used to simulate the actions and interactions of agents as well as the dynamic interactions between agents and their environments in order to gain an understanding of the functioning of the system (Axtell & Epstein, 1994; Bonabeau, 2002). Several agent-based models (Batty, 2003; Haklay, O'Sullivan, Thurstain-Goodwin, & Schelhorn, 2001; Helbing, Farkas, Molnar, & Vicsek, 2002; Ronald, Sterling, & Kirley, 2007; Turner & Penn, 2002; Willis, Gjersoe, Havard, & Jon Kerridge, 2004) have been applied to study pedestrian behavior. However, these models largely focus on how people move around small areas or within buildings, and how people's movements are influenced by fine-level features such as design and layout of buildings and streets. Our model, by contrast, focuses mainly on the choice of travel mode without detail on route or fine-scale change in environment along the route. Only recently, ABMs have been used to study how the social and built environments shape travel mode choice, including walking and transit behaviors (Lu, Kawamura, & Zellner, 2008; Yang & Diez-Roux, 2013; Yang, Diez Roux, Auchincloss, Rodriguez, & Brown, 2011, 2012; Yang, Diez-Roux, Evenson, & Colabianchi, 2014; Zhu et al., 2013).

We developed an ABM of utilitarian walking and use the model to explore questions relevant to understanding the factors affecting population-level patterns of walking to destinations (henceforth called utilitarian walking) and income variations in walking, and the plausible impacts of selected interventions. Specifically we explore utilitarian walking under various levels of residential segregation and spatial distributions of land uses and safety from crime. We investigate how travel cost can alter prevalence of walking and income differentials in utilitarian walking under various segregation scenarios. In addition we explore the synergistic effects of policies aimed at changing attitudes towards walking and driving (such as educational policies) with travel cost policies. Section 2 describes model design, scenarios analysis, and model validation. Results are presented in Section 3. Sections 4 and 5 discuss and conclude the findings, respectively.

2. Research method

2.1. Model design

The model simulates adults' daily utilitarian travel. Our intent was to capture the core elements and basic dynamics that could be relevant to our research questions regarding the impact of travel costs on utilitarian walking and the socioeconomic disparities in walking. For parsimony, the model includes only adults' travel behaviors on work days (no weekends). Seasonal variations and weather are ignored. The model assumes sidewalks are present and walkable.

The model is an extensive revision of a previously published model (Yang et al., 2011, 2012). The previous model had a simple mode choice algorithm (in which individuals chose to walk or travel by car) and four feedbacks. Travel cost was excluded from the travel mode choice function and public transit was not included as a travel mode in this earlier model. We modified the model to allow three travel modes (walking, car, and bus transit) and incorporated a number of theoretically and empirically justified feedbacks for each. We also adapted the model to make it more suitable to questions related to walking variation by income level. Fig. 1 shows the model's framework. It is a time-discrete model with each time step being one day. The model was developed in Java and Repast.

2.1.1. City, persons, and locations

The model represents a city of 64 km^2 (8 km by 8 km) with an $800 * 800$ grid space, where each cell of size $10\ m * 10\ m$ is either occupied by a location (i.e. a place with a social function) or is empty. The city has 400 equal-sized neighborhoods, each composed of $40 * 40$ cells.

Model agents are 100,000 adults grouped into 50,000 households (population density 1563/sq km). Each household includes two adults. Income quintiles are assigned to each household randomly from 1 (lowest) to 5 (highest). Following the US distribution of automobile ownership by income quintile, the percentages of households having no vehicle are 26.5%, 5.0%, 2.3%, 0.9% and 1.5% (Pucher & Renne, 2003) for the five income level groups (from the lowest to the highest), respectively. A person's social network includes the other household member and up to nine friends who are randomly selected from the same workplace (three), the same neighborhood (three), and people with the same income level in the city (three) (Carroll, 2004). At baseline, each individual is assigned an attitude value towards each travel mode (described below). These attitudes change over time as a function of various feedbacks.

The city has a number of residences and non-residential locations (workplaces, shops, social places and restaurants) with constant ratios to the total population (see Table 1 and Fig. 2). The city has a symmetrical transportation network centered in the city center. Three east–west bus lines and three north–south bus lines cross each other with 2 km of the interval distance among bus lines both east–west and north–south. Each bus route covers 4 km with bus stops at 400 m intervals to reflect that in US urban areas the distance between bus stops is in the range of 200–600 m