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Effects of the built environment on automobile-involved pedestrian crash frequency and risk

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ABSTRACT

This area-based study explores the relationship between automobile-involved pedestrian crash frequency versus risk and various built environment factors such as road network and land use. The methodology involves the use of Bayesian hierarchical intrinsic conditional autoregressive model, which accounts for unobserved heterogeneities and spatial autocorrelations. The city of Seattle is selected for this empirical study, and the geospatial unit of analysis is traffic analysis zone. The primary data were obtained from collision profiles available at the Seattle Department of Transportation. The major findings of this study include: (1) the densities of 4-way intersections and more than 5-way intersections and land use mixture are positively correlated with the pedestrian crash frequency and risk; (2) sidewalk density and the proportion of steep areas are negatively associated with the pedestrian crash frequency and risk; (3) areas with a higher bus stop density are likely to have more pedestrian crashes; (4) areas with a greater proportion of industrial land use have lower pedestrian crash frequency; (5) areas with an averagely higher posted speed limit has higher pedestrian crash risk; (6) areas with a higher employment density has lower pedestrian crash risk; (7) the mode share of walking and the total number of trips are positively correlated with the pedestrian crash frequency, and the total number of trips is negatively correlated with the pedestrian crash risk. These findings provide support for planning policy-making and road safety programs. Local authorities should improve walkability by providing more sidewalks and separate travel lanes for motorized traffic and pedestrians in areas with different land use purposes. Compact development should be encouraged to support building a safe walking environment.

1. Introduction

Walking is an environmentally friendly and healthy transportation mode. Its intrinsic value can never be overexaggerated. When combined with other factors such as diversity, activities, and sense of place, walking can generate positive externalities, which make our streets and even our cities attractive (Jacobs, 1993). If cities want to become a better place for residents and visitors, a built environment that is safe, fun to walk, and friendly for or to pedestrians is also indispensable (Mustafa and PE;Birdsall, 2014). However, in the process of urbanization and motorization, the built environment tends to become less and less friendly to and safe for pedestrians. At present, walking has become more vulnerable than ever, even in developed countries such as the United States (The National Highway Traffic Safety Administration, 2012). As dependence on cars increased, pedestrian travel has gradually stepped down as an unpopular mode of choice. From 1980 to 2010, the percentage of walking commuters in the United States, for instance, steadily decreased from 5.60% to 2.77% (American Association of State Highway and Transportation Officials and US Department of Transportation, 2013). For work-related trips, walking is mostly unattractive. However, as obesity rate increases, the importance of walking as a mode that encourages physical activity is being gradually rediscovered across nations, and much has been done to promote walking (Frank and Engelke, 2001; Pucher and Buehler, 2010). Walking is largely advocated by the public, because it has high potential to mitigate environment and health challenges that our society is facing (Newman and Kenworthy, 2006; Saelens et al., 2003).

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Policy makers and urban planners advocate developing new urban communities that promote sustainable cities through encouraging smaller lots, more mixed land use, denser blocks, and higher street connectivity (Ellis, 2002; Lee and Moudon, 2006; Lund, 2003). The livable neighborhoods have better proximity to amenities such as open spaces, parks, grocery stores, and jobs, which contribute to a higher mode share of walking (Ellis, 2002; Lund, 2003). Ideally, the popularity of walking could be highly enhanced by improved pedestrian safety and well-planned walking environments. Therefore, the attractiveness of walking has been highlighted in the ideas of new urbanism and smart growth (Ellis, 2002; Lund, 2003). However, the role of pedestrian safety is still being paid little attention.

In fact, pedestrians are vulnerable road users. For instance, in the United States, 4743 pedestrians were killed and 76,000 pedestrians were injured in 2012, and pedestrian deaths accounted for 14% of all traffic fatalities, despite that the facts that walking only accounts for a negligible share of all modes of travel and the number of pedestrians is relatively smaller than the numbers of drivers and passengers (The National Highway Traffic Safety Administration, 2012). Efforts have been made by policy makers to promote safe walking environments. Taking Seattle as an example, the Seattle Department of Transportation (SDOT) issued a pedestrian master plan to develop strategies to decrease the number of pedestrian collisions and severe injuries. The proposed countermeasures included maintaining pedestrian visibility at intersections, improving crossing conditions, and regulating driving speed limits (Seattle Department of Transportation, 2009).

The role of the built environment in explaining the causes of pedestrian crashes has been continually investigated (The National Highway Traffic Safety Administration, 2012). Existing studies have linked aspects of the road network and pedestrian safety across different spatial scales. For micro-level studies, an overall finding is that intersections have more pedestrian crashes, because there are more conflict points among travelers and vehicles (Ukkusuri et al., 2012). The importance of conducting micro-level research is that its results can efficiently inspire countermeasures for safety improvements. However, micro-level studies only catch the intersection or midblock characteristics as pieces of road elements, while macro-level studies understand a city as a complex system. In addition, specific crash site′s location is often "scaled up" to an intersection or midblock in practice. Therefore, the corresponding built environment features often lack accuracy, and fixed covariates could be biasedly measured when road features along a road segment are not constant. Area-based studies examine the relationship between the built environment and pedestrian crashes at a larger geospatial scale, where data are richer and more accurate, which help produce more stable estimates and capture aggregated effects of more covariates on pedestrian crashes and related risks.

This study contributes to the existing studies on the following three aspects. First, it innovatively includes the forecasted number of trips as a denominator to measure pedestrian crash risk, which can help planners better evaluate and even change factors affecting pedestrians' crash risks and safety in advance. It compares the variation between a frequency model and a risk model, thus providing a fuller picture of pedestrian safety and crash risk. Second, by examining the effects of several commonly used density measures in existing studies, this study explores whether the effects are similar in terms of size and direction in a new setting. Third, it examines whether pedestrian crash frequency and risk have spillover effects, which have not been examined before according to the authors' knowledge. Last but not the least, building on existing studies, this study is designed to identify the effects of land use and road network features on pedestrian safety.

In particular, this study investigates the built environment factors that are associated with pedestrian crash frequency versus pedestrian crash risk at a macro level. It considers quite a few area-based covariates that have not been considered before in existing studies, such as forecasted walking trips. Two Bayesian hierarchical intrinsic conditional autoregressive (ICAR) models accounting for unobserved heterogeneities and spatial autocorrelations were developed to evaluate the pedestrian crash frequency and risk across traffic analytical zones (TAZs) in Seattle, Washington. It hypothesizes that compact developed urban environment is safer. Although a higher pedestrian crash frequency could be observed in dense urban settings, the pedestrian crash risk could be actually lower. The independent variables include various factors of the road network, land use, sociodemographics, and travel demand. This study begins with a literature review and research design, describes the methodological details, presents the results of the ICAR models, and ends with conclusions, a discussion, and future research.

2. Literature Review

Conventionally, traffic engineers and health professionals use the 5E′s and Haddon′s matrix to analyze crash and injury outcomes and to propose safety improvement strategies. The 5E′s analytical tool refers to Environment, Engineering, Enforcement, Education, and Emergency aid (Bergman et al., 2002; Morrison et al., 2003). Haddon′s matrix, as a standardized framework, is made of host, agent, event, and environment (Runyan, 2015). Both of these conceptual models highlight the importance of the built environment in explaining pedestrian crashes occurring in urban settings.

2.1. Key Definitions

In most cases, a "pedestrian crash" refers to an automobile intersecting with a pedestrian. "Crash frequency" is the number of collisions at a certain location per unit time. "Crash risk" is often calculated by the number of collisions reported per 1000 trips, 1000 h, or 1 km of exposure (de Geus et al., 2012).

2.2. Effects of Built Environment Factors

The built environment plays an important role in explaining crash and injury outcomes (Ding et al., 2015). A number of studies have examined the relationship between built environment factors and pedestrian crash frequency versus risk at multiple geospatial scales. The scales include signalized intersections (Miranda-Moreno et al., 2011; Pulugurtha and Sambhara, 2011), state or city routes (Moudon et al., 2008, 2011), census tracts (Narayanamoorthy et al., 2013; Ukkusuri et al., 2011, 2012; Wang and Kockelman, 2013; Wier et al., 2009), zip code boundaries (Ukkusuri et al., 2011, 2012), and TAZs (Siddiqui et al., 2012). For studies conducted at the point or the polyline level, such as intersections and state routes, a commonly observed bias is that those studies cannot cover all geographical areas. For example, intersection-based studies cannot identify risk factors of pedestrian collisions that occur at midblocks.