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Modeling spatial relationships between multimodal transportation infrastructure and traffic safety outcomes in urban environments

Ivana Tasic [a,*], Richard J. Porter [b]

[a] Department of Civil and Environmental Engineering, University of Utah, 110 Central Campus Dr., Rm. 1650, Salt Lake City, UT 84112, United States
[b] Department of Civil and Environmental Engineering, University of Utah, 110 Central Campus Dr., Rm. 2000, Salt Lake City, UT 84112, United States

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ABSTRACT

The interest in multimodal transportation improvements in urban areas is increasing in cities across the U.S. Improved access to multimodal transportation attracts new users, but can possibly increase their exposure to risk from crashes, particularly in areas where the "safety in numbers" phenomenon does not exist. The relationship between access to multimodal transportation and safety in urban environment is complex, as non-motorized user vulnerability becomes a predominant risk factor when they are involved in a crash, even at lower vehicle speeds. This paper aims to evaluate the relationship between multimodal transportation infrastructure, expressed through the presence of multimodal facilities and user exposure, and traffic safety outcomes. Using Chicago as a case study, a comprehensive dataset is developed that significantly contributes to the existing literature by including socio-economic, land use, road network, travel demand, and crash data. Area-wide analysis on the census tract level provides a broader perspective about safety issues that multimodal users encounter in cities. Negative-binomial regression models with fixed and random effects are estimated to account for data overdispersion and spatial effects. Total vehicle-only crashes, total crashes with non-motorized users, and fatal vehicle-only crashes are modeled. The results show strong association between the variables related to multimodal transportation availability and usage, and both motorized and non-motorized crashes. Although simplified in terms of some spatial correlation assumptions, demonstrated methods prove to be a beneficial and computationally efficient tool for estimating and easily interpreting modeled relationships. Further research efforts to address the limitations of the presented approach are proposed.

1. Introduction

Cities across the U.S. have increased their interest in multimodal transportation investments aimed at improving accessibility to multimodal transportation options. There is a general understanding that improved multimodal transportation systems will contribute to resolving multiple long-term issues related to sustainability and efficiency of travels in urban environments.

This movement toward more active and diverse transportation options in U.S. cities was followed by the development of policies and guidelines for multimodal transportation, and the need to extend existing evaluation methods to account for the presence of different modes and their impacts on transportation performance (NACTO, 2014, 2013; ITE, 2010). Improved access to multimodal transportation attracts new users of alternative transportation modes, but may create an environment for more frequent or severe crashes by increasing exposure of more vulnerable road users. Some have argued, however, that a "safety in numbers" phenomenon takes effect in areas of high non-motorized user activity due to changes in motorized user expectations and behaviors (Elvik, 2013, 2009; Bhatia and Wier, 2010).

In urban environments where multimodal transportation thrives, the relationship between access to multimodal transportation and safety is complex. Transportation funding programs require that investments primarily focus on transportation performance, including establishing quantitative transportation safety targets. With this need to quantify safety outcomes, evaluation methods need to account for additional factors associated with multimodal safety in urban environments.

This paper explores the relationship between access to multimodal transportation and safety outcomes in urban environments. Data from the City of Chicago are used to quantify this relationship. An extensive dataset is built by merging data obtained from a variety of sources. Chicago is considered a promising U.S. case study

* Corresponding author.
E-mail addresses: ivanat@trafficlab.utah.edu (I. Tasic), richard.jon.porter@utah.edu (R.J. Porter).

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due to its developed complete streets initiatives and extensive multimodal transportation network features. The goal is to account for various factors that impact multimodal safety in urban areas: spatial features, socio-economic characteristics, land use mixture, street network patterns, and multimodal facilities, among others. The analysis is conducted on the census tract level to capture area-wide effects on safety outcomes, measured by expected crash frequencies of different types and severities.

The next section of this paper includes a literature review and describes the research objectives. The third section is focused on data sources and organization, while the fourth section describes the methodology. The results are discussed in the fifth section, while the final section of the paper covers conclusions, and recommendations.

2. Literature review

Transportation mode choice and the presence of multimodal infrastructure are among the factors that could influence the future of road safety (Hauer, 2005). Crashes involving pedestrians and bicyclists, or vulnerable road users, have become an international concern (Wei and Lovegrove, 2012), especially in urban environments where these road users' vulnerability if involved in a crash is a predominant risk factor (Wegman et al., 2008; Elvik et al., 2009). The Highway Safety Manual (HSM) recognizes that "increasing the availability of mass transit reduces the number of passenger vehicles on the road and therefore a potential reduction in crash frequency may occur because of less exposure" (Highway Safety Manual, 2010). Availability and access to multimodal transportation options in urban environments is likely to play a key role in the way safety is estimated and evaluated in these environments for motorized and non-motorized transportation modes.

While the majority of the existing predictive methods in road safety focus on vehicular traffic as the most dominant mode of transportation, evaluation of non-motorized safety and related impact factors has been occurring on the zonal and regional levels (Zeng and Huang, 2014; Siddiqui et al., 2012; Quddus, 2008; Washington et al., 2006). There are several reasons why road safety in general is explored on this "macroscopic" level. It is quite common that safety-influencing factors such as roadway and roadside geometrics, pavement conditions, and traffic control are best explored on the segment or intersection-level (Highway Safety Manual, 2010), but there is an increasing interest among researchers to explore some other area-wide factors that can be addressed in spatial analysis (Aguero-Valverde, 2013). Also, the current crash modification factors (CMFs) have "methodological drawbacks" due to the fact that applied modeling techniques do not account for spatio-temporal heterogeneity exhibited by crashes (Chen and Persaud, 2014; Xu et al., 2014; Li et al., 2013; Aguero-Valverde, 2013; Plug et al., 2011; Huang and Abdel-Aty, 2010; Karlaftis and Tarko, 1998). Some other applications of crash modeling, such as identifying crash risk hotspots, network screening, and safety planning are becoming more relevant with legislative requirements to incorporate multimodal safety performance goals into long-term planning processes (MAP 939, 2014; Jiang et al., 2014; Coll et al., 2013; Vieira Gomes, 2013; Park and Young, 2012; Siddiqui et al., 2012; Yiannakoulias et al., 2012; Plug et al., 2011; Montella, 2010; Anderson, 2009; Pulugurtha et al., 2007; Washington et al., 2006; Persaud et al., 1999; Nicholson, 1998; Hauer, 2005). These initiatives also lend themselves to analysis at a spatial level in some cases.

Crash data in spatial analyses are aggregated within traffic analysis zones (Siddiqui et al., 2012), neighborhoods (Wang and Kockelman, 2013), census-based units (Quddus, 2008; Noland and Quddus, 2004), or counties (Flask and Iv, 2013; Li et al., 2013; Yannis et al., 2008; Aguero-Valverde and Jovanis, 2006). Regional safety modeling may raise the issue of the Modifiable Area Unit Problem (MAUP), which could cause changes in statistical inference if spatial analysis units change, and can be handled by reducing the number of analyzed regions (Xu et al., 2014; Openshaw, 1984). Spatial aggregation of crash data may also lead to ecological fallacy, when the relationship between aggregated variables is attributed to established aggregation methods, the effect which may be corrected by using lower levels of aggregation (Davis, 2004, 2002). If traffic analysis zones are used to aggregate the data, there are indications that "internal" and "near boundaries" crashes need to be treated separately (Siddiqui et al., 2012). The existing evaluations at various levels of spatial aggregation show that some analysis units such as census tracts are more reliable than the others in terms of providing more repeatable estimation results (Ukkusuri et al., 2012). Procedures to conduct intersection- and segment-level analysis to identify high-risk sites with a potential for safety improvement have been well-documented (e.g., Yu et al., 2014; Wang and Abdel-Aty, 2006), but a higher level of spatial aggregation, such as that reported in this paper, can be used to account for area-wide factors which may influence safety outcome in multimodal environments.

Another typical concern in spatial analysis of traffic safety is determining the adequate exposure variables, and this was addressed by using both surrogate and conventional exposure variables depending on data availability. The exposure variables in existing studies include variables such as population (Ukkusuri et al., 2012), presence of jobs as trip generators (Noland and Quddus, 2004), network attributes and land use data (Shankar et al., 2003), estimated walk miles traveled for pedestrian crashes (Wang and Kockelman, 2013; Lee and Abdel-Aty, 2005), estimated bicycle traffic (Vandenbulcke et al., 2014), length of road (Zeng and Huang, 2014; Quddus, 2008; Noland and Quddus, 2004), and vehicle miles traveled (Li et al., 2013; Aguero-Valverde and Jovanis, 2006). Previous spatial analyses of crashes focused on both motorized (Aguero-Valverde, 2013; Li et al., 2013; Siddiqui et al., 2012) and non-motorized crashes (Wang and Kockelman, 2013; Quddus, 2008; Shankar et al., 2003), accounting for variables that somewhat represent the availability of alternative transportation modes (Wang and Kockelman, 2013; Yiannakoulias et al., 2012; Quddus, 2008; Schneider et al., 2004). Limited numbers of these studies focus only on urban environments and account for more detailed features of multimodal street networks (Moeinaddini et al., 2014; Quddus, 2008).

New applications of crash models and the exploration of additional factors that could impact traffic safety of a variety of users has led to the development of spatial modeling techniques that analyze crashes on a selected level of spatial analysis units (Vandenbulcke et al., 2014; Xu et al., 2014; Aguero-Valverde, 2013; Wang and Kockelman, 2013). The majority of these "spatial" road safety studies found that it is appropriate to consider spatial correlation among analyzed entities in crash prediction models (Zeng and Huang, 2014; Aguero-Valverde, 2013; Castro et al., 2013; Siddiqui et al., 2012; Wang et al., 2009; Quddus, 2008). More recent research involves using Bayesian rather than classical statistical inference to develop spatial models for motorized and non-motorized crashes at various levels of spatial aggregation (Huang and Abdel-Aty, 2010; Miranda-Moreno et al., 2007; Aguero-Valverde and Jovanis, 2006; Miaou and Song, 2005). As concluded in the previous studies, Fully Bayesian (FB) models are either consistent with Negative Binomial (NB) models (Aguero-Valverde and Jovanis, 2006) or outperform models that do not account for the multilevel structure of crash data (Wang and Kockelman, 2013; Siddiqui et al., 2012; Huang et al., 2009). Robustness and transferability of multilevel models applied in safety analysis are issues that are still scarcely addressed (Huang and Abdel-Aty, 2010).