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Exploring the safety in numbers effect for vulnerable road users on a macroscopic scale

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ABSTRACT

A "Safety in Numbers" effect for a certain group of road users is present if the number of crashes increases at a lower rate than the number of road users. The existence of this effect has been invoked to justify investments in multimodal transportation improvements in order to create more sustainable urban transportation systems by encouraging walking, biking, and transit ridership. The goal of this paper is to explore safety in numbers effect for cyclists and pedestrians in areas with different levels of access to multimodal infrastructure. Data from Chicago served to estimate the expected number of crashes on the census tract level by applying Generalized Additive Models (GAM) to capture spatial dependence in crash data. Measures of trip generation, multimodal infrastructure, network connectivity and completeness, and accessibility were used to model travel exposure in terms of activity, number of trips, trip length, travel opportunities, and conflicts. The results show that a safety in numbers effect exists on a macroscopic level for motor vehicles, pedestrians, and bicyclists.

1. Introduction

One of the general concerns about investing and planning for more sustainable multimodal transportation infrastructure is the increase in exposure of road users who are vulnerable to crashes. However, as cities grow and develop, robust multimodal systems are required to enable adequate integration of land use and transportation, and provide viable travel options for nondriving populations. This is where the concept of Safety in Numbers emerges, supported by the assumption that more multimodal travel options would lead to more walking and cycling, which would be associated with an increase in crashes, but less than proportional with the increase in walking and cycling (Elvik, 2016).

This paper explores the existence of a Safety in Numbers effect in the context of a major city in the U.S., relying on a detailed dataset on multimodal infrastructure, and using a combination of exposure measures. The goal of the paper is to determine whether the effect of

Safety in Numbers exists on a macroscopic level, for vehicular users, pedestrians and bicyclists. The research aims to contribute to the current literature on urban safety and inform the practice of planning for multimodal solutions with consideration of safety effects.

This paper uses data from Chicago aggregated at the census tract level, to estimate the expected number of vehicle-only (vehicular), vehicle-pedestrian (pedestrian), and vehiclebicyclist (bicyclist) total and injurious (severe) crashes. Generalized Additive Models (GAM) are used in the areal safety modeling framework to model these six crash types and address the potential effects of spatial autocorrelation in spatially aggregated data. Measures of exposure are derived from travel demand model estimates and complemented by proxies for exposure that include the representation of multimodal infrastructure and accessibility.

The following section of the paper reviews literature on the safety in numbers effect, as well as the interaction between it and the provision of infrastructure facilitating multimodal trips. The data and methods are described in the third section of the paper, while the results and the discussion follow in section four. The final section provides summary of research findings and recommendations for the future research focusing on vulnerable road users on the macroscopic level.

2. Literature review

One of the first studies that focused on discovering whether the Safety in Numbers effect exists, used data from Oakland, California, to examine the relationship between pedestrian volume and the rate of pedestrian-vehicle crashes (Geyer et al., 2006). That study and many later studies have confirmed the existence of a safety in numbers effect, but one needs to know the mechanisms producing the effect if one aims to exploit it in planning infrastructure to encourage walking or cycling

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Table 1
Data Sources, Descriptions, and Formats.

Data	Source	Year
Crash records	Illinois DOT, Chicago Crash Browser	2005–2012
Socio-economic characteristics	U.S. Bureau of Census, ACS 5-Year Estimates	2008–2012
Land use	Chicago Metropolitan Agency for Planning	2010
Road network	City of Chicago	2012
Travel demand model	Chicago Metropolitan Agency for Planning	2010
Other traffic volume data	Illinois DOT	2014
L Train lines, stops and ridership	Chicago Transit Authority	2012
Bus lines, stops and ridership	Chicago Transit Authority	2012
Bike lanes and bike racks	City of Chicago	2012
Sidewalk	City of Chicago	2012
Commuter trips to work by means	U.S. Bureau of Census, ACS 5-Year Estimates	2008–2012
Spatial units of analysis	City of Chicago	2012

(Bhatia and Wier, 2011). The early studies on safety in numbers focused on pedestrians (Geyer et al., 2006; Bhatia and Wier, 2011). There are fewer studies focusing on bicyclists (Johnson et al., 2014; Fyhri et al., 2017), and even fewer studies that include both pedestrians and cyclists (Elvik, 2016). Previous research generally concludes that a deeper understating and more knowledge on Safety in Numbers effect is required (Bhatia and Wier, 2011; Elvik and Bjørnskau, 2017).

More recent studies attempt to demonstrate the safety in numbers effect on a macroscopic scale for potential use in planning and predictions at the Traffic Analysis Zone level, but again only focus on a single group of road users (Wang and Kockelman, 2013). Macroscopic studies in road safety have been conducted to capture area-wide and system-wide effects that may influence the expected number of crashes for multimodal road users and thus become particularly relevant in the field of transportation safety planning (Abdel-Aty et al., 2013; Lee et al., 2015a,b). These studies go beyond intersection and corridor-level analysis typical for statistical road safety models that focus on vehicles, and explore the effects of transportation network patterns on vulnerable road users safety (Cai et al., 2016; Wang et al., 2016; Guo et al., 2017). With the development and the implementation of macroscopic road safety studies, statistical analysis methods used in these studies continued to improve and rely on both frequentist and Bayesian statistical inference (Lee et al., 2015a,b; Amoh-Gyimah et al., 2016; Nashad et al., 2016).

This paper focuses on exploring whether a "safety in numbers" effect exists for pedestrians and cyclists in a major U.S. city, when safety is evaluated at a macroscopic level.

3. Methodology

The City of Chicago served as a case study, and data aggregation on the census tract level helped with capturing the integration of land use mixture and multimodal transportation system features. Census tract is a unit defined by the U.S. Bureau of Census, as a "small, relatively permanent statistical subdivision of a county" updated with each decennial census program implementation. A total of 801 census tract s from Chicago served as the sample for developing crash prediction models on a macroscopic scale, and exploring the safety in numbers effect. Data sources used in this study are provided in Table 1.

The measures of exposure used in this study are a combination of measures obtained from city transportation agencies and measures developed by the research team. The areal safety modeling framework relied on GAM developed for all six crash types addressed, as this approach enables modeling of non-linear relationships and was found to be a good alternative based on frequentist statistical inference in earlier studies (Tasic et al., 2016). The results of the areal safety models served to explore whether there is a safety in numbers effect present for multimodal road users.

3.1. Data collection

As shown in Table 1, the combination of official transportation agency data sources as well as open source data platforms enabled the development of a dataset consisting of roughly one hundred variables that represent the variety of factors potentially influencing safety in major U.S. cities. Data collected included crashes, multimodal transportation features (i.e. features facilitating the use of more than one mode of transportation on a given trip), road network features and traffic conditions, land use data, socio-economic characteristics, and spatial features supporting the selection of appropriate spatial units of analysis. Data were obtained from the Illinois Department of Transportation (DOT), Chicago Metropolitan Agency for Planning (CMAP), Chicago Transit Authority (CTA), City of Chicago, U.S. Bureau of Census, as well as the available open data platforms supported by the City of Chicago.

3.2. Variables and measures

The variables and measures developed from the data collected for this study can be divided into crash-related variables, exposure variables, surrogates for exposure, and variables that represent area-wide effects that influence crashes. This study uses six crash-related outcome variables to model vehicle-only (vehicular) total crashes, vehicular fatal and injury (severe) crashes, pedestrian total crashes, pedestrian severe crashes, bicyclist total crashes, and bicyclist severe crashes. Total number of vehicular and nonmotorized trips estimated through the City of Chicago Air Quality Conformity Study conducted by CMAP served as primary measures of vehicular, pedestrian, and bicyclist exposure. As these are estimates, and additional proxies for exposure were needed to represent locations with a high concentration of activity and potential for conflicts, data on multimodal infrastructure and accessibility measures served as surrogates for exposure. In particular, accessibility measures that reflect the ease of reaching specific destinations via walking, biking, and transit mode were developed using the methods from previously published research on multimodal accessibility (Tasic et al., 2014a,b). These accessibility metrics were not developed in correlation with the traditional exposure measures. Rather than relating to traffic volumes of multimodal users, these metrics represent locations where there is more potential for interaction between multimodal users. In addition, the complexity of urban environment in major cities was captured by adding the variables on socioeconomic characteristics and land use. All these variables were aggregated on the census tract level, as this was found to be the most appropriate unit of analysis for the purpose of this study, due to compatibility with socio-economic data, general data availability, as well as the size of the unit that adequately captures the characteristics of multimodal transportation systems. Table 2 provides the complete list of variables used in the statistical modeling process. All continuous variables were normalized using the census tract area to obtain the density metrics. The relatively small variation in census tract size enabled the development of the statistical model specifications that include both normalized and non-normalized metrics.

3.3. Statistical area safety models

Several approaches based on both frequentist and Bayesian statistical inference were explored in the statistical area safety modeling context, particularly making sure that they account for spatial autocorrelation that may appear when the data are spatially aggregated. Spatial safety studies conducted in the past prove that Bayesian Hierarchical Models have the ability to deal with various issues that