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Evaluating the impact of bike network indicators on cyclist safety using macro-level collision prediction models

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ABSTRACT

Many cities worldwide are recognizing the important role that cycling plays in creating green and livable communities. However, vulnerable road users such as cyclists are usually subjected to an elevated level of injury risk which discourages many road users to cycle. This paper studies cyclist-vehicle collisions at 134 traffic analysis zones in the city of Vancouver to assess the impact of bike network structure on cyclist safety. Several network indicators were developed using Graph theory and their effect on cyclist safety was investigated. The indicators included measures of connectivity, directness, and topography of the bike network. The study developed several macro-level (zonal) collision prediction models that explicitly incorporated bike network indicators as explanatory variables. As well, the models incorporated the actual cyclist exposure (bike kilometers travelled) as opposed to relying on proxies such as population or bike network length. The macro-level collision prediction models were developed using generalized linear regression and full Bayesian techniques, with and without spatial effects. The models showed that cyclist collisions were positively associated with bike and vehicle exposure. The exponents of the exposure variables were less than one which supports the “safety in numbers” hypothesis. Moreover, the models showed positive associations between cyclist collisions and the bike network connectivity and linearity indicators. In contrast, negative associations were found between cyclist collisions and the bike network continuity and topography indicators. The spatial effects were statistically significant in all of the developed models.

1. Introduction

Many cities worldwide are recognizing the important role that cycling plays in creating green and livable communities and have implemented policies to encourage cycling. However, vulnerable road users such as cyclists are usually subjected to an elevated level of injury risk which discourages many road users to cycle. As such, developing a safe and efficient bike network can attract more road users to cycle for a range of activities.

Road safety has often been managed in a reactive manner where existing problems, that occur after a road has been designed and built, are targeted. Recently, researchers have advocated a more proactive approach that addresses road safety before problems emerge (de Leur and Sayed, 2003). This can be achieved by making safety a priority from the outset of the transportation and land use planning process. One main obstacle associated with the delivery of a proactive road safety measure is the lack of reliable tools to evaluate road safety in a proactive manner (de Leur and Sayed, 2003). The main goal of this paper is to develop empirical tools that can be used for proactive cyclist safety evaluation. Macro level collision prediction models (CPMs) have been widely used as a decision tool for the proactive safety evaluation of transportation networks. CPMs attempt to explain the relationship between collisions occurrence and various network characteristics (traffic, geometry, etc.). They have diverse applications such as: evaluating the effectiveness of safety improvement measures, detection and ranking of accident-prone locations, and estimating the safety potential of facilities (Sawalha and Sayed, 2001). Among the macro-level CPM studies that investigated cyclist collisions, some have focused on bike route types (Harris et al., 2011; Chen et al., 2012; Teschke et al., 2012; Kaplan and Prato, 2015), while others have focused on zonal characteristics such as the built environment and land use (Siddiqui et al., 2012; Wei and Lovegrove, 2013; Chen, 2015). Although important efforts were utilized in these studies to associate wide range of variables to cyclists' collisions, none of the previous studies comprehensively addressed the impact of the bike network structure on cyclist safety. The study of networks is an area of research under

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which any transport network can be visualized as a graph that is composed of a set of links and nodes. Accordingly, various network properties can be investigated based on the relationship between the network elements (i.e. the links and nodes); and new network indicators can be estimated.

This study discusses the development of macro level CPMs for 134 traffic analysis zones (TAZs) at the city of Vancouver, British Columbia. The models are developed using generalized linear modeling (GLM) and full Bayesian (FB) techniques, and explicitly incorporate new indicators related to the connectivity, directness, and topography of the city of Vancouver bike network. In addition, the actual cyclist exposure (bike kilometers travelled and vehicle kilometers travelled) is used as opposed to relying on exposure proxies such as the population or the bike network length. Spatial effects among the different TAZs are also studied using the developed Bayesian models.

2. Literature review

2.1. Safety models for cyclists

Various studies have discussed cyclist safety at an aggregate level. Jacobsen (2003) examined the relationship between the number of vulnerable road users (pedestrians and cyclists) and their collisions with motor vehicles based on five data sets from different locations worldwide. Results showed that, at the population level, the number of motorists colliding with vulnerable road users would increase at approximately 0.4 power of the number of people cycling or walking. Robinson (2005) studied three datasets from Australia, and concluded similar results to the Jacobsen's study. Kim et al. (2007) explored various crash, roadway, land, and environmental factors contributing to the injury severity of cyclists, who were involved in cyclist-motorist crashes in North Carolina. Their results showed that several factors increased the probability of a fatal injury in a crash, including head-on collisions, speeding, inclement weather, no streetlights, morning peak, truck involvement, intoxicated drivers/cyclists, and age. Kim et al. (2010) also discussed results from macro level CPMs, which suggested that demographic variables, accessibility variables, bus route length, and number of intersections were positively associated with cyclist-vehicle collisions. Wei and Lovegrove (2013) developed community-based negative binomial models for cyclist-vehicle collisions. The models revealed an increase in the cyclist collisions with the increase of the total lane kilometers, bike lane kilometers, bus stops, traffic signals, intersection density, and arterial–local intersections percentage. More recently, Chen (2015) indicated that zonal bike crash frequencies are spatially correlated. His study included some cycling related variables that had not been investigated in prior studies such as bike trips vs. total trips, zonal mean of the driving speed limits, zonal mean slopes, and densities of street trees and parking signs. He found that the zonal mean of driving speed limits, total number of trips, length of on-arterial bike lanes, entropy of mixing land use, and density of traffic signals were positively associated with cyclist collisions. Lastly, Kaplan and Prato (2015) modeled the frequency and the severity of crashes involving cyclists and motorists in the Copenhagen region by estimating a link-based multivariate Poisson-lognormal model. The model underlines the relevance of infrastructure, land use, and spatial effects to explain the variation in the number of cyclist–motorist collisions. They showed that the number of crashes was nonlinearly related to the average bike and vehicle daily traffic, which confirms the safety in numbers hypothesis (Elvik, 2009; Jacobsen, 2003). Kaplan and Prato (2015) also found that bike paths are associated with less crashes, which agrees with recent studies that show that cycling facilities increased actual and perceived safety (De Rome et al., 2014; Kaplan et al., 2014), and is in disagreement with past literature that assume that cycling in mixed traffic is safer than cycling on bike infrastructure (Pucher et al., 1999; Rodgers, 1997).

2.2. Graph theory

Graph theory concepts originated from the "Seven Bridges of Konigsberg" problem, which was solved by Euler in the 18th century. Garrison and Marble (1962) applied graph theory to transportation networks, and were able to develop indices for connectivity. Kansky (1963) presented indices that characterized network connectivity and complexity. More recently, Gattuso and Mirello (2005) were able to evaluate the topology and geography of metro networks in some European cities and New York City based on graph indicators. Derrible and Kennedy (2010) presented a new methodology to draw metro networks as graphs, and accordingly they were able to create directness and structural connectivity indicators. Quintero-Cano et al. (2014) introduced a novel approach to redraw transit networks as graphs, and hence they were able to include new connectivity indicators. Those indicators were used in developing macro-level CPMs to assess the safety of Metro Vancouver transit network (Quintero et al., 2013).

Previous studies that developed macro-level bike collision models used proxies for the cyclist exposure due to data limitations, e.g. (Wei and Lovegrove, 2013; Amoh-Gyimah et al., 2016). Moreover, many of the studies did not use any exposure measure for motorized traffic, e.g. (Siddiqui et al., 2012; Chen, 2015). These two limitations can lead to biased results since exposure is one of the most important factors affecting collision occurrence. As well, although some studies investigated the association between road network patterns and the safety of vulnerable road users (Zhang et al., 2015; Wei and Lovegrove, 2012), almost none of the former macro-level cyclist safety studies incorporated a comprehensive set of indicators, representing the bike network structure, and their impact on cyclist safety. This study attempts to address these shortcomings in order to develop reliable and rigorous macro-level cyclist safety models.

3. Data collection

3.1. Data sources

In this study, zone-level CPMs are developed based on 134 TAZs at the city of Vancouver. The CPMs included explanatory variables that represent the cycling network attributes. Exposure due to bike and vehicle traffic volumes is also included. Data is compiled for analysis using ArcGIS after being extracted from four main sources:

1. Insurance Corporation of British Columbia, a public automobile insurance company, provided the collisions data for the city of Vancouver for a 5 years period (2009–2013). Only cyclist-vehicle collisions are included in the analysis, as shown in Fig. 1, to prevent any bias that may occur if other types of collisions are considered. A 5 years period is selected to obtain an adequate sample size of collisions. The sample included 3 severity levels, i.e. fatality, injury, and property damage only. However the total number of collisions is used in the analysis in order not to reduce the sample size. The data did not include collisions between cyclists-pedestrians and cyclists with each other. Although this can be a limitation (Chen, 2015), it should be noted that these collisions are typically rare and not usually reported in Vancouver.
2. Translink, the Metro Vancouver transportation authority, provided geocoded files of the bike network, the street network, and the TAZs boundaries. Moreover, Translink provided the out-