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Multimodal injury risk analysis of road users at signalized and non-signalized intersections

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ABSTRACT

This paper proposes a multimodal approach to study safety at intersections by simultaneously analysing the safety and flow outcomes for both motorized and non-motorized traffic. This study uses an extensive inventory of signalized and non-signalized intersections on the island of Montreal, Quebec, Canada, containing disaggregate motor-vehicle, cyclist and pedestrian flows, injury data, geometric design, traffic control and built environment characteristics in the vicinity of each intersection. Bayesian multivariate Poisson models are used to analyze the injury and traffic flow outcomes and to develop safety performance functions for each mode at both facilities. After model calibration, contributing injury frequency factors are identified. Injury frequency and injury risk measures are then generated to carry out a comparative study to identify which mode is at greatest risk at intersections in Montreal. Among other results, this study identified the significant effect that motor-vehicle traffic imposes on cyclist and pedestrian injury occurrence. Motor-vehicle traffic is the main risk determinant for all injury and intersection types. This highlights the need for safety improvements for cyclists and pedestrians who are, on average, at 14 and12 times greater risk than motorists, respectively, at signalized intersections. Aside from exposure measures, this work also identifies some geometric design and built environment characteristics affecting injury occurrence for cyclists, pedestrians and motor-vehicle occupants.

1. Introduction

Urban mobility and safety for all modes of transportation are key elements in the development of sustainable cities. Reaching this goal requires the implementation of multimodal approaches and a shift towards non-motorized modes of transportation, namely walking and cycling.

Despite the health and environmental benefits, choosing walking or cycling as the desired mode exposes cyclists and pedestrians to safety risks. Motor-vehicle collisions are an important cause of death and injury worldwide. Over 2000 people, motor-vehicle occupants, motorcyclists, cyclists and pedestrians are killed each year on Canadian roads (Transport Canada, 2010). The likelihood of fatal and severe injuries are, in general, greater for pedestrians and cyclists than for motor-vehicle occupants (Beck et al., 2007). In 2010, 73% of road injuries occurred in urban areas in Canada (Transport Canada, 2010). In urban settings, the majority of pedestrians and cyclists are injured at intersections. Urban intersections are a complex area of the road network where many different interactions can occur between motor-vehicles, cyclists and pedestrians. Road safety at urban intersections, for all modes, is therefore an important issue.

Despite the important body of literature, important gaps still exist in data collection methods, data integration and modeling approaches. In particular multimodal safety approaches at the city level are missing in the literature. Previous research has described the overall number of road injuries or fatalities, without making any distinction between the road user types. Additionally, past studies have considered single outcomes, such as the safety of cyclists, pedestrians, or motorized traffic and few have integrated all these modes. Also, the effect of geometric design and built environment characteristics related to the layout and location of the intersections being studied, have not been tested.

Motor-vehicle occupant and pedestrian injury risk at intersections have been studied for decades, but empirical evidence for cyclist risk at intersections is scarce. Furthermore, little is known

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about the contributing environmental factors associated with injury risk across users (cyclist, pedestrian and motor-vehicle). Instead of focusing only on one mode of travel and identifying sites in need of improvement, this study considers cyclists, pedestrians and motor-vehicle occupants and applies a multimodal approach. A multimodal approach can help build more comprehensive safety portraits, since the injury risk of each travel mode is simultaneously determined. Thus, if intersection characteristics are found to increase crashes for cyclists and pedestrians, for example, safety improvements can be carried out for both modes at once. A multimodal approach may ease the task of selecting sites for safety improvement interventions as well as potentially provide a more economically viable solution, compared to separated analysis and interventions for pedestrians and cyclists. Finally, empirical evidence regarding the risk imposed by motor-vehicles on non-motorized users at intersections is mostly limited to signalized intersections, which only represent a minority of urban intersections. The inclusion of non-signalized intersections would help to better understand the safety issues of non-motorized users in urban settings and provide a complete portrait of all intersections within a city.

In this paper, we seek to provide additional evidence on the abovementioned research issues using as an application environment the city of Montreal, Quebec, Canada. This paper aims to (i) develop injury occurrence models, (ii) estimate the risk for all road users using a Bayesian modeling approach, (iii) carry out a comparative analysis between the injuries, levels of flow and risk across the three modes (cyclist, pedestrian and motor-vehicle) and two facilities (signalized and non-signalized intersections), and (iv) investigate the impact of motor-vehicle traffic on cyclist and pedestrian safety at intersections.

This paper is broken down into several sections. Section 2 offers a literature review. Section 3 describes the methodology followed by the site selection and data in Section 4. Section 5 discusses the results and Section 6 presents the conclusions drawn from this study as well as directions for future work and limitations.

2. Literature review

Road safety in urban environments is a topic that has been growing in the literature. In recent years, this extensive literature has dealt with many issues ranging from data collection methods, data integration and modeling approaches. Despite all these efforts, multimodal safety approaches at the city level are missing in the literature. Some studies have looked at multiple injury severity outcomes of motor-vehicles (minor, major and fatalities, for instance).However, to our knowledge, no studies have looked at multiple road user outcomes (cyclist, pedestrian and motorized outcomes). Most studies have looked at single crash outcomes.

For instance, cyclist safety studies examining the factors affecting crash occurrence have been published (Brüde and Larsson, 1993; Elvik, 2009; Jacobsen, 2003; Miranda-Moreno et al., 2011b; Wang and Nihan, 2004). To date, most cyclist safety studies have been carried out in European and Asian cities and while a few have been carried out in the United States and in Australia, these have mainly focused on cyclist injuries at the city or town level and did not focus on intersections (junctions) as the unit of study (Elvik, 2009). Pedestrian and motor-vehicle safety studies in North America are not as rare. For studies focusing on pedestrian-vehicle collisions at intersections, we can refer to the works of Cameron (1982), Brüde and Larsson (1993), Lyon and Persaud (2002), Shankar et al. (2003), Lee and Abdel-Aty (2005), Harwood et al. (2008) and Miranda-Moreno et al. (2011a) and for vehicle-vehicle collisions, refer to Boufous et al. (2008) and Chin and Quddus (2003).

Among the studies focusing on intersections as the unit of analysis, the majority of these considered signalized and not non-signalized intersections. Among the studies addressing safety at non-signalized intersections in urban environments, we can mention the work of Sayed and Rodriguez (1999); few studies however have provided safety portraits and models for both types of intersections in the same city.

While these previous studies are useful for identifying the factors contributing to cyclist, pedestrian and motor-vehicle injury occurrence, these have been modeled separately and few attempts have been made to combine these into a multimodal approach. Some studies in the literature have addressed level-of-service, delay or comfort for cyclists, pedestrians and motor-vehicles from a multimodal perspective (Dowling et al., 2008; Guttenplan et al., 2001) however safety has received less attention in the literature.

One study in the United States compared the injury risk between different modes (Beck et al., 2007) based on the observed injuries and exposure in terms of daily person-trips. This study did not consider factors other than exposure which may also be determinants of injury occurrence. The results identified that motorcyclists, cyclists and pedestrians are more at risk of being fatally injured (58.3, 2.3 and 1.5 times more, respectively) compared to motor-vehicles. However in terms of injuries, motor-vehicle occupants account for the majority of fatal and non-fatal injuries. Another study carried out in the United Kingdom sought to investigate the risk of cycling in absolute terms and with respect to other modes of transportation (Wardlaw, 2002). Per kilometre travelled, pedestrians witnessed a greater level of fatalities due to motor-vehicle collisions than cyclists. Wardlaw (2002) emphasizes that cycling is not a dangerous mode of transportation and the belief that it is in fact dangerous is not based on evidence.

In addition to modeling injury occurrence, it is important to obtain a basis for which the safety at each location and for each mode can be compared. Recent studies have defined and applied a Bayesian Hierarchical approach to identify hazardous locations (Brijs et al., 2007; Miaou and Song, 2005; Schlüter, 1997; Tunaru, 2002; Van den Bossche et al., 2002). Many applications of the multivariate Poisson hierarchical model with covariates and time–space random effects have also been documented in the road safety literature. For a comprehensive literature review, refer to Lord and Mannering (2010). Bayesian models are very popular in the road safety literature since posterior risk estimates can be computed easily. Risk estimates can then be used to identify intersections, corridors or areas at high risk.

Among the most popular posterior risk estimates are the posterior mean number of injuries, the posterior injury rate, the potential for injury reduction, the posterior distribution of ranks and the posterior probability that a site is the worst (Miaou and Song, 2005; Miranda-Moreno, 2006; Schlüter, 1997). Despite this extensive literature, little effort has been made to use Bayesian methods to identify dangerous intersections for cyclists and pedestrians while also correcting for explanatory variables such as traffic conditions and controls as well as geometric design and built environment characteristics. In addition to identifying hotspots for specific modes or for total road accidents, it is important to know which modes are most at risk and where. If, for example, locations where cyclists are most at risk are locations where pedestrians are also at risk, this influences what type of treatments should be proposed and implemented. The task becomes more complex when the high-risk sites for different modes do not overlap.

In response to the research questions and gaps in the literature, this study applies a multimodal approach to study cyclist, pedestrian and motor-vehicle safety at both signalized and non-signalized intersections using Bayesian multivariate Poisson models.