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Analysis of vehicle-bicycle interactions at unsignalized crossings: A probabilistic approach and application

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ABSTRACT

In the last decades, bicycle usage has been increasing in many countries due to the potential environmental and health benefits. Therefore, there is a need to better understand cyclists' interactions with vehicles, and to build models and tools for evaluating multimodal transportation infrastructure with respect to cycling safety, accessibility, and other planning aspects. This paper presents a modeling framework to describe driver-cyclist interactions when they are approaching a conflicting zone. In particular, the car driver yielding behavior is modeled as a function of a number of explanatory variables. A two-level hierarchical, probabilistic framework (based on discrete choice theory) is proposed to capture the driver's yielding decision process when interacting with a cyclist. The first level models the probability of the car driver perceiving a situation with a bicycle as a potential conflict whereas the second models the probability of yielding given that a conflict has been perceived by the driver. The framework also incorporates the randomness of the location of the drivers' decision point. The methodology is applied in a case study using observations at a typical Swedish roundabout. The results show that the conflict probability is affected differently depending on the user (cyclist or driver) who arrives at the interaction zone first. The yielding probability depends on the speed of the vehicle and the proximity of the cyclist.

1. Introduction

Public agencies around the world promote bicycle usage because of the potential environmental and health benefits (Edwards and Mason, 2014; Fishman et al., 2012). In Stockholm, for example, the number of cyclists has increased more than 100% in the last 20 years for trips crossing the city cordon (Börjesson and Eliasson, 2012). In order to promote bicycle usage, the Swedish government has established two main goals: (i) make bicycling safer; and (ii) increase the bicycling share as a mode of transport (Trafikverket, 2011). To accomplish these goals the Swedish Transport Administration and cities traffic departments have made considerable efforts to introduce safe bikeways and improve the bicycle network accessibility and associated facilities.

However, bicycling in many cases is at a disadvantage as a viable transportation mode due to lack of network accessibility, impact of weather conditions, safety, and lack of support for multimodal trips that include bicycling as one of the modes. Recently, some of these disadvantages have been addressed with the introduction of bicycle sharing systems (*BSS*), which allow for spatial and temporal usage and multimodal connectivity providing for short-term one-way transportation. Once properly introduced, *BSS* can provide support for opportunistic trips complementing public transport networks (Vogel et al., 2011). Such systems have been introduced in more than 400 cities around the world, and many other cities are also planning their introduction (Faghih-Imani et al., 2014; Frade and Ribeiro, 2014; Jäppinen et al., 2013).

Network accessibility is often a serious impediment that reduces bicycle use. In order to increase bicycle usage a well-connected bicycle network is essential. Common accessibility problems include pavement condition, network discontinuities, bus-stops blocking bicycle lanes or paths, congestion, work zones, and in general interactions with vehicles (Gustafsson and Archer, 2013). Therefore, infrastructure planning, maintenance programs, and policies and regulations are important factors to create a good environment for cycling. For example, in Europe higher costs of car ownership, limited parking spaces, car-free zones, traffic calming measures, and lower speed limits encourage bicycle usage (Pucher et al., 2010).

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Cyclists are vulnerable road users, and cycling safety is an essential concern in traffic planning. Among others, the interaction with motorized vehicles has attracted a lot of attention. For instance, one of the most common vehicle-bicycle accidents is with driver turning right and cyclists approaching from behind on the right side of the driver (Räsänen and Summala, 1998). Kim et al. (2007) state that speed is the key factor for serious and fatal outcomes in vehicle-bicycle accidents. Furthermore, children and elderly cyclists are at most risk. The authors find that higher vehicle flows and higher cyclist volumes increase the accident rate. On the other hand, the authors state that the proper design of bicycle facilities (e.g., illumination and wider paths) is an important means to improve cyclist safety. Minikel (2012) points out that higher speeds, higher traffic volumes, and presence of heavy vehicles are detrimental to cyclist safety. Different transport facilities have also been evaluated for cyclist safety. For instance, at roundabouts, vehicle speed and the age of the roundabout are important predictors of bicycle related accidents (Hels and Orozova-Bekkevold, 2007).

At unsignalized intersections governed by priority rules, the interaction between car drivers and cyclists is often based on expectations. For example, drivers often yield to cyclists. Björklund, 2005 states however, that sometimes the expectations of the road users can be wrong: some fail to look for a specific road user (e.g. failing to give way) and some fail to look in some specific direction. T-junctions are examples where car drivers usually fail to fulfil other road users' expectations. For instance, drivers, when approaching from the connecting street and turning right at T-junctions, pay more attention to cars coming from the left and less to cyclists and pedestrians on the right (Björklund, 2005).

It has been reported in the literature that the most frequent accident type occurring in interactions between bicycles and vehicles is that of the car turning right and meeting a cyclist approaching from behind on the right side of the driver (Räsänen and Summala, 1998). In a later study, Räsänen and Summala (2000) also report that vehicles travelling at a high speed fail to look for cyclists. According to the literature, high speed vehicles have lower probability to yield to cyclists due to less time to detect and react to the cyclists' presence (Silvano et al., 2014, 2015). In Sweden, in about 42% of the cases drives do not yield to cyclists (Svensson and Pauna, 2010). Furthermore, the common expectation in vehicle-bicycle interactions at unsignalized intersections, including roundabouts with crosswalks, is that drivers exiting the roundabout yield to cyclists. However, drivers may fail to fulfil such expectation due to lack of attention (e.g. drivers do not realize the presence of the cyclist due to limited vision or lack of attention). Cyclists may also misinterpret the situation (often assuming that drivers are aware of their presence). These cases have been documented in the traffic safety literature as 'looked-but-failed-to-see-errors' (Herslund and Jörgensen, 2003). In addition, cyclists overestimate by a factor of 2 the distance at which they would be recognized by drivers (Wood et al., 2009).

Although the interaction between drivers and cyclists is important for traffic safety, the decision process of a driver to yield to a cyclist is not well understood and has received little attention in the literature. The main objective of this paper is to develop a theoretical framework to model the driver-cyclist interaction process and apply it to a specific case where actual data of such interactions were collected.

The rest of the paper is organized as follows: Section 2 presents a theoretical framework using a probabilistic approach to model the driver yielding decision process; Section 3 illustrates the proposed methodology through an application in modeling vehicle yielding probability at a typical roundabout in Stockholm using actual data collected at the facility; Section 4 discusses the corresponding results, and Section 5 concludes the paper.

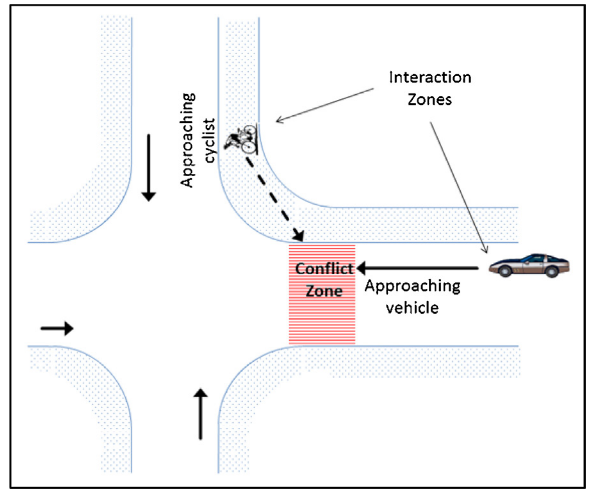

Fig. 1. Vehicle-bicycle approaching a conflict zone.

2. Methodology

2.1. Vehicle-bicycle interaction and driver yielding decision process

Vehicle-bicycle interaction is triggered by the potential collision course on which the vehicle and bicycle would have been involved if current trajectories had been maintained. Normally, at unsignalized intersections and roundabouts in urban environments, the areas where vehicle and bicycle trajectories intersect are the crosswalks. Therefore, the crosswalk is considered as the *Conflict Zone (CZ)* where the vehicle and bicycle trajectories may intersect with a potential collision. In order to avoid an accident due to potentially intersecting trajectories, a driver's decision process begins at some distance upstream the *CZ* with the driver deciding whether the situation presents a potential conflict or not. If drivers perceive the interaction as a potential conflict, they have to further decide whether to yield or not. The decisions are impacted by, among other factors, the vehicle and bicycle speeds, the vehicle and bicycle relative distances to the crossing, etc. Vehicle and bicycle *Interaction Zones (IZ)* are also defined and their lengths may differ depending on geometric design and other factors. Fig. 1 depicts a vehicle and bicycle interaction as they approach a conflict zone at a typical unsignalized crossing.

For the purposes of this paper, the decision process by the driver to yield to the bicycle is a hierarchical process as follows:

- A conflict decision (C) with potential collision.
- A yielding decision (Y) given that the conflict is perceived by the driver.

The conflict decision (C) is not observed, and is modeled as a latent state. On the other hand, the yielding decision can be observed i.e., a driver stops or adjusts the speed to allow a cyclist to traverse safely the conflict zone. The point where the yielding decision process commences is also not observable and varies from driver to driver and impacted by the actual conditions. It is therefore, modeled as a random variable following a given distribution whose parameters can be estimated from observation of the trajectories and yielding decisions.

The driver-cyclist interactions are similar in some aspects to pedestrian-car interactions. In the pedestrian case, driver behavior has been explained by factors such as vehicle speed, relative position of the pedestrian, pedestrian platooning and geometric characteristics (Schroeder and Rouphail, 2011). However, the two