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Drivers overtaking bicyclists—An examination using naturalistic driving data

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A B S T R A C T

This paper demonstrates a unique and promising approach to study driver-bicyclist interactions from a driver's perspective by using in-vehicle sensory data from naturalistic driving studies. A total of 4789 events of drivers overtaking bicyclists were extracted from an existing naturalistic driving study in Michigan, United States. The vehicle lateral placement at the time of passing bicyclists was used as a surrogate safety measure. A number of factors were examined, including the lane marking type, the presence of a bike lane or paved shoulder, the presence of traffic, lane width, and driver distraction. Some notable findings include that (1) when a bike lane or paved shoulder was present, a dashed non-center line (i.e., a dashed line separating two lanes in the same direction) was associated with significantly less vehicle lane-crossing and closer distance to the bike lane/shoulder compared to a solid centerline; (2) an alarming 7.8% of the overtaking occurred when the drivers were distracted within five seconds prior to passing bicyclists. From a bicyclist's perspective, that translates to one overtaken by a distracted driver for every thirteen times they are overtaken. In addition, drivers manipulating a cell phone were associated with significantly less vehicle lane-crossing when overtaking bicyclists. The results of this work could be potentially used by traffic engineers, policymakers and legislators to support the designs of better road infrastructures, education programs, policies, and traffic laws that aim to improve the safety of all road users. The quantitative results could also be potentially used as a baseline to develop and benchmark automated vehicle technologies on how to interact with bicyclists on the road.

1. Introduction

Bicycling has long been an important mode of transportation for its economic, environmental, and health benefits. In recent years there has been a growing trend of bicycling in Europe and the United States (McKenzie, 2014; Pucher and Buehler, 2017). The growth of bicycling is likely to increase even more with innovations such as electric bikes and bike sharing (Pucher and Buehler, 2017). Despite all the benefits, bicyclists are vulnerable road users (VRUs) who get little protection in a crash with motor vehicles. The safety issues of riding a bicycle on roadways have been a growing concern. In the European Union countries, 2043 cyclists were killed in road accidents in 2015, accounting for 7.8% of all road fatalities (CARE, 2017). In the same year, 818 pedalcyclists were killed and an additional estimated 45,000 injured in motor vehicle crashes in the United States (National Highway Traffic Safety Administration (NHTSA), 2017). A study by Pucher and Dijkstra (2003) found that bicyclists in the United States were twelve times more likely than car occupants to get killed (72 vs 6 fatalities per billion kilometers), and bicyclists in the United States are twice as likely to get killed as bicyclists in Germany and over three times as likely as bicyclists in Netherland. The perceived danger of cycling in motorized traffic has been a major deterrent to more bicycling in the United States and Europe (Jacobsen et al., 2009).

Among all types of crashes involving bicyclists, a motorist approaching a bicyclist from behind is particularly dangerous and much more likely to result in serious injuries and fatalities. An early investigation by Cross and Fisher (1977) found that motorist overtaking bicyclists (Problem Type 13) accounts for 24.6% of fatal bicycle/motor-vehicle crashes and 4.0% non-fatal crashes. More recently, NHTSA Fatality Analysis Reporting System (FARS) started to use a more detailed coding manual (National Highway Traffic Safety Administration (NHTSA, 2016) for pedestrian and bicyclist fatal crashes, which includes coding for the bicycle crash types (PB30B: Crash type - bicycle). The crash types include four categories that involve "Motorist Overtaking Bicyclist": (1) "Undetected bicyclist", (2) "Misjudged Space", (3) "Bicyclist swerved", and (4) "Other/unknown". The latest data in 2016 show that three of the "motorist overtaking" categories were ranked in the top four most common bicyclist fatal crash types (National Highway

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Traffic Safety Administration (NHTSA), n.d.): The most common crash type is “Motorist Overtaking - Other/Unknown” (108 (13%) bicyclist fatalities), followed by “Motorist Overtaking - Undetected Bicyclists” (73 (9%) bicyclist fatalities), “Parallel Path - Other/Unknown” (62 (7%) bicyclist fatalities), and “Motorist Overtaking - Misjudged Space” (58 (7%) bicyclist fatalities). The most common type of “Motorist Overtaking - Other/Unknown” also seems to suggest the complexity and difficulties of determining the causes of overtaking crashes from post-crash investigations. An independent study by the League of American Bicyclists also shows that rear-end collisions accounted for 40% of the 481 bicyclist fatalities that they investigated (League of American Bicyclists, 2014). In any case, it is evident that drivers overtaking bicyclists is one of the most problematic crash types.

Promising solutions to reduce bicycle-related crashes and conflicts include developing safer infrastructures, evidence-based guidelines and regulations, effective education and training programs for drivers and bicyclists, and advanced driver/bicyclist support technologies. However, the development of such solutions depends on a good understanding of how drivers and bicyclists interact with each other in dynamic driving/riding scenarios. Given the importance of the issue, efforts have been made by researchers to investigate the drivers’ overtaking maneuver using objective data. One common study method involves using instrumented bicycles with cameras and sensors to measure objective data such as the overtaking proximity, GPS location, and bicycle speed, and collecting the data by riding the instrumented bicycle on public roads (e.g., Walker, 2007; Shackel and Parkin, 2014). Some other studies used covert cameras or tape strips with pneumatic tubes on the roadside to record overtaking behaviors at fixed locations (e.g., Jilla, 1974; Kroll and Ramey, 1977; Duthie et al., 2010; Kay et al., 2014). Some recent studies also used a driving simulator with virtual bicyclists (Hamann et al., 2016; Bella and Silvestri, 2017).

From these studies, it is generally believed that drivers’ overtaking maneuver is affected by a range of factors involving the bicyclist, road configuration, traffic, and vehicle: (1) bicyclist factors: riding position on the road (Walker, 2007; Savolainen et al., 2012), apparent gender (Walker, 2007; Chuang et al., 2013), riding alone or in a group (Savolainen et al., 2012), helmet use (Walker, 2007, Note this factor was argued by Olivier and Walter (2013) as not significant), and handling of wheel angle, speed and speed variation (Chuang et al., 2013); (2) road and traffic factors: lane width (Shackel and Parkin, 2014), presence of bike lane (Parkin and Meyers, 2010; Chapman and Noyce, 2012; Mehta et al., 2015), presence of centerline (Shackel and Parkin, 2014) and centerline rumble strips (Savolainen et al., 2012), road markings (Shackel and Parkin, 2014; Mehta et al., 2015), posted speed limits (Parkin and Meyers, 2010), road vertical grade (Chapman and Noyce, 2012), road surface conditions (Chuang et al., 2013), oncoming traffic (Savolainen et al., 2012; Shackel and Parkin, 2014), far lane traffic (Mehta et al., 2015), presence of a “Share the Road” sign (Kay et al., 2014); (3) vehicle factors: vehicle size and type (Walker, 2007; Chapman and Noyce, 2012; Parkin and Meyers, 2010; Shackel and Parkin, 2014; Chuang et al., 2013; Mehta et al., 2015).

Most of these studies used the passing distance (i.e., the lateral clearance between the vehicle and bicyclist while the vehicle is passing) as the main surrogate safety measure. A recent work by Schindler and Bast (2015) proposed a model that divides a driver’s maneuver of overtaking a bicyclist into four consecutive phases of *approaching*, *steering away*, *passing*, and *returning*. Together with the work by Dozza et al., 2016, they recorded overtaking maneuvers in Sweden using an instrumented bicycle equipped with a LIDAR. They identified three distinct overtaking strategies of *flying* (keeping vehicle speed relatively constant), *accelerative* (slowing down and following the bicyclists for some time before passing), and *piggybacking* (following a lead vehicle). All the aforementioned studies are important in gaining insights into a driver’s overtaking maneuver. However, most data collected from the instrumented bicycles or roadside cameras lack the continuous and high time-resolution data about the driver operations and vehicle movements. Given that during the overtaking the driver is the main decision maker in selecting the timing of the overtaking, and setting the vehicle lateral displacement and speed, it may be of great value to examine the overtaking from the driver’ perspective by directly examining a driver’s maneuver of the vehicle during overtaking using naturalistic driving data.

Driver distraction has been a significant contributing factor in road crashes. In the United States in 2015, distracted driving accounted for 3477 fatalities (10% of overall fatalities) and an estimated 391,000 injuries (16% of all the injured people) (National Center for Statistics and Analysis, 2017). In addition, these numbers are likely under-reported due to the difficulties in identifying driver distraction during the post-crash investigation. A naturalistic driving study shows driver distraction accounted for 23% of all crashes and near-crashes (Klauer et al., 2006). The National Occupant Protection Use Survey (NOPUS) on driver electronic device use observed 1600 roadway sites and 48,177 vehicles in the United States in 2016, and reported that 3.3% of passenger vehicle drivers at the observation sites were holding cell phones to their ears while driving and 2.1% of the drivers were visibly manipulating handheld devices while driving (Pickrell and Li, 2017). Reed and Ebert (2016) manually coded driver activities in 9856 video frame samples from a naturalistic driving study (Safety Pilot Model Deployment (SPMD), the same naturalistic driving study that was used in this paper). It was found that the drivers had a phone in their right hands in 6.5% of the video frame samples, in their left hands in 2.6% of the samples, and on their laps in 2% of the samples. A distracted driver poses a great danger not only to him/herself but also to the surrounding road users, especially the VRUs such as bicyclists and pedestrians. However, to our knowledge, few studies investigated the prevalence of driver distraction that directly poses danger to VRUs.

Another application of studying driver-bicyclist interaction is in the development of automated vehicle technologies. One critical challenge in developing automated vehicles is that they need to share the existing infrastructure with non-motorized road users such as bicyclists and pedestrians (Ziegler et al., 2014). Given the complexity of the real-world road environment and human-to-human interactions between the drivers and bicyclists, it is a complicated and crucial area to study how the automated vehicles should be programmed to interact with these road users both safely and efficiently. One promising way to help answer this question is to observe how human drivers interact with the non-motorized road users and use the resulting objective data as potential baselines and benchmarks to support the development of automated vehicles when interacting with bicyclists (Delp et al., 2015).

Naturalistic driving studies typically use instrumented vehicles to continuously record a wide variety of high time-resolution data of the driver, vehicle, and road environment. The vehicles were driven by study participants for their everyday trips in an unsupervised and unobtrusive manner. The data collected in these studies have been valuable in helping researchers to understand many aspects of driver behaviors such as drivers’ acceptance and adaptation to in-vehicle safety systems (Sayer et al., 2011), driver distraction (Bao et al., 2015; Feng et al., 2017a; Li et al., 2017), driver aggressiveness (Feng et al., 2017b), and driver parking search behavior (Hampshire et al., 2016).

The main objective of this paper is to demonstrate the approach and value of studying driver-bicyclist interaction by using naturalistic driving data and examine whether and how drivers’ overtaking maneuvers are affected by a number of factors. Specifically, we examined the effects of left-side lane marking type, the presence of a bike lane or paved shoulder, the presence of left-side traffic, lane width, and driver distraction. The drivers’ overtaking maneuver is measured by the vehicle lateral placement at the time of passing the bicyclist. The two surrogate safety measures are (1) vehicle lane-crossing distance to the left-side lane (simply referred to as “lane-crossing distance” hereinafter) and (2) vehicle lateral distance to the bike lane/shoulder marking.