Accident Analysis and Prevention 74 (2014) 33–41

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

A hazard-based duration model for analyzing crossing behavior of cyclists and electric bike riders at signalized intersections

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ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form 2 October 2014
Accepted 9 October 2014
Available online xxx

Keywords:
Cyclist
Electric bike
Red-light running
Waiting time
Hazard-based duration model
Intersection

ABSTRACT

This paper presents a hazard-based duration approach to investigate riders' waiting times, violation hazards, associated risk factors, and their differences between cyclists and electric bike riders at signalized intersections. A total of 2322 two-wheeled riders approaching the intersections during red light periods were observed in Beijing, China. The data were classified into censored and uncensored data to distinguish between safe crossing and red-light running behavior. The results indicated that the red-light crossing behavior of most riders was dependent on waiting time. They were inclined to terminate waiting behavior and run against the traffic light with the increase of waiting duration. Over half of the observed riders cannot endure 49 s or longer. 25% of the riders can endure 97 s or longer. Rider type, gender, waiting position, conformity tendency and crossing traffic volume were identified to have significant effects on riders' waiting times and violation hazards. Electric bike riders were found to be more sensitive to the external risk factors such as other riders' crossing behavior and crossing traffic volume than cyclists. Moreover, unobserved heterogeneity was examined in the proposed models. The finding of this paper can explain when and why cyclists and electric bike riders run against the red light at intersections. The results of this paper are useful for traffic design and management agencies to implement strategies to enhance the safety of riders.

1. Introduction

Cycling is one of the most popular modes of transportation in some Asian developing countries, such as Cambodia, India and China. Cycling still constitutes a substantial proportion among all travel modes in China. For example, regular bicycles (18.2%) and electric bikes (20.5%) were used for about 38.7% of trips in Shanghai in 2010 (City News in Shanghai, 2011). In developed countries, cycling is considered as a sustainable travel mode (Gatersleben and Appleton, 2007; Lawson et al., 2013). The advantages of cycling are energy efficient, healthy, quiet and compatible with the urban scale (Menghinia et al., 2010). Although bike is still a minority travel mode, the share rate of bicycle commuting has increased over the last decade in most developed countries (Chaurand and Delhomme, 2013). For example, the American Community Survey in 2008 showed that the City's share of bike commuters had a full 48% increase from its 2000 level of 0.61% to 0.90% in eight years (Los Angeles Department of City Planning, 2011). Two-thirds of all Australian households had two or more working bicycles in 2009 (Australian Bureau of Statistics, 2009).

Electric bikes (e-bikes) are expanding rapidly in China in the recent ten years. Due to its labor-saving and speed, e-bike has quickly become as a popular mode of travel in many Chinese cities (Weinert et al., 2007). There were more than 160 million e-bikes in China in 2012 (Jinling Evening Newspaper, 2013). E-bikes are defined as electric two-wheelers with relatively low speeds and weights compared to motorcycles. Motorcycles are strictly restricted in urban areas of most large cities in China (Wu et al., 2012). In China, e-bikes are classified as non-motor vehicles and are given access to the bicycles' infrastructure (Lin et al., 2008).

Riders are considered as vulnerable road users, because they are unprotected in traffic crashes (ETSC, 1999). Cyclists often infringe on the traffic rules and have a higher likelihood of traffic collisions compared to pedestrians and drivers (Wegman et al., 2012). Two-wheeled riders involved in injuries and fatalities are overrepresented in traffic collisions. In 2010, 11,562 riders and their passengers of non-motorized vehicles died and 47,220 were severely injured, representing 17.7% of the total traffic deaths and 18.6% of injuries in Chinese road accidents (CRTASR, 2010). From

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http://dx.doi.org/10.1016/j.aap.2014.10.014
0001-4575/

6432 cyclist collisions in Victoria, Australia between 2004 and 2008, 33.9% resulted in severe injury of the cyclist (Boufous et al., 2012). About 2100 cyclists were killed in road accidents in 2010, representing 7.2% of all traffic fatalities recorded in the 24 EU countries (ETSC, 2012).

A cycle network is only as good as its weakest features and these are often the junctions (ETSC, 1999). In North Carolina, USA, 50.2% of bicycle–motor vehicle accidents occurred at intersections (Kim et al., 2007). Riders' red-light infringement is a type of highly dangerous behavior occurring at intersections. Due to the weakness of safety awareness and enforcement, red-light infringement behavior is rather prevalent, and represents a substantial safety problem at Chinese urban intersections (Wu et al., 2012).

So far, many scholars have studied the red-light crossing behavior at intersections. Most focused on pedestrian red-light violation behavior. Some useful reviews of the existing research on pedestrian street-crossing behavior can be found in Papadimitriou et al. (2009). However, only a few studies have been conducted on the red-light running behavior of cyclists, much less to electric two-wheelers. Johnson et al. (2011) used video cameras to investigate the violation rate and risk factors of cyclists' red-light infringement at urban intersections in Melbourne, Australia. The results showed cyclists turning left were more likely to infringe on the red light compared to cyclists running straight through the intersection.

Furthermore, Johnson et al. (2013) investigated various risk factors of cyclists' red-light crossing behavior in Australia by conducting a survey on the internet. The results indicated that male, young, and cyclists with no crash experience had a larger likelihood of violating traffic lights. Their findings suggested that some cyclists were motivated to infringe by their safety perception and that infrastructure factors had significant effects on the red-light running behavior.

Wu et al. (2012) used logistic model to study behavior characteristics and associated factors of red-light running for two-wheeled riders in China. The results indicated that gender, age and conformity behavior had significant effects on the cyclist' violation, and classified the red-light crossing behavior to three types: obey the rules (44%), risk-taking (31%), opportunistic (25%). However, logistic models cannot be used to investigate riders' waiting endurance times and violation hazards (i.e., instantaneous failure rate or conditional failure rate).

Zhang and Wu (2013) used two video cameras to investigate the effect of sunshields on red-light infringement behavior of cyclists and e-bikers in the city of Hangzhou, China. Their results suggested that sunshields installed at intersections can reduce red-light infringement rates of cyclists and e-bikers on both sunny and cloudy days.

Till now, however, no studies addressed the waiting times of two-wheeled riders. The waiting process is crucial to riders in the street-crossing behavior. Once riders terminate their waiting processes during the red light period, they would infringe on the traffic signal and put themselves in danger. The waiting process can be regarded as a continuous-time state which is affected by internal and external factors. Special attention should be given to riders' waiting durations and violation hazards.

In this study, hazard-based duration approach was proposed to investigate riders' red-light running behavior. This approach can be used to describe the duration of a certain state and how various factors affect the duration. What is more, it can take into account censored data, which improves the accuracy to measurement. Duration models have been widely applied in biometrics, social science, and industrial engineering fields to determine causality in duration data. In the transportation field, they have been used to study many time-related events including travel activity, traffic accident duration, and automobile ownership (Bhat, 2000; Chang and Yeh, 2007; Chung, 2010; Hensher and Mannering, 1994; Hojati et al., 2013; Van den Berg et al., 2012).

In recent years, several scholars have applied hazard-based duration approach to investigate pedestrian crossing behavior at signalized intersections. Hamed (2001) used parametric hazard models to analyze pedestrians' waiting times at signalized intersections in Jordan. The results revealed that pedestrians' expected waiting time influenced the number of attempts needed to successfully cross the street. Tiwari et al. (2007) applied the non-parametric Kaplan–Meier method to study pedestrians' violation behavior at signalized intersections in India. The results showed pedestrians would not like to wait for a long time to cross the street. Pedestrians would become impatient and violate the traffic signal as pedestrians' waiting times increase. Wang et al. (2011), and Guo et al. (2011, 2012) used proportional hazards models to investigate pedestrian red-light infringement behavior and the associated risk factors at unban intersections in Beijing. The results showed that human factors and the external environment had significant effects on pedestrians' street-crossing behavior. However, they did not investigate the duration of waiting times of two-wheeled riders. Besides, unobserved heterogeneity was not considered in the existing research about pedestrian waiting times.

The first aim of this study is to provide an effective and practical methodology for investigating riders' waiting times, violation hazards and associated risk factors. The second aim is to explore the differences in waiting times, violation hazards, and the effects of associated factors between cyclists and e-bikers. The finding of this paper can explain when and why cyclists and e-bikers infringe on the traffic signal at intersections. The results might help to provide solutions to enhance the safety of two-wheeled riders, which is a major issue in some developing countries in general and China in particular.

2. Model

The variable of interest in duration analysis is the length of time that elapsed from the beginning of an event until its end (Nam and Mannering, 2000). In this study, the length of time is the waiting duration of a rider who arrives at the intersection during the red light period. The waiting time for each rider was taken as the difference between the arrival time when he/she arrives at the intersection and the departure time when he/she begins to cross the intersection. The waiting time can be classified into uncensored data and censored data. It is defined as uncensored data if the rider terminates the waiting duration to cross the intersection during the red light period. Otherwise, it is considered as censored data as long as the rider terminates the waiting duration to cross the intersection during the green light period. The maximum of waiting endurance is unknown for the censored data, because the real waiting endurance may be longer than the waiting time which is terminated by the presence of the green light (Guo et al., 2011).

This waiting duration is a continuous random variable T with a cumulative distribution function $F(t)$. $F(t)$ is also known as the failure function and gives the probability that a rider has the red-light running behavior before some specified waiting time t. Conversely, the survival function, $S(t)$, is defined as the probability that a rider waits longer than some specific time t.

$$S(t) = \Pr(T > t) = 1 - \Pr(T \le t) = 1 - F(t) \quad (1)$$

The survival function is known as the endurance probability or survivor probability.

The hazard function $h(t)$ of duration time T gives the conditional failure rate. This is defined as the probability of failure during a