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RESEARCH PAPER

A Probability Model of Bicycles Crossing Vehicle-bicycle Separation Lines

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Abstract: Vehicle-bicycle separation lines are frequently used to isolate motor vehicles from bicycles on China's urban roads. Conflict between motor vehicles and bicycles exists in these road sections. It is regularly caused by bicycles crossing the vehicle-bicycle separation line onto the motor vehicle lane. Thus, it is imperative to research the probability of crossing travel of bicycles. First, two presumptions for bicycles to cross travel are stated. One is that bicycles need to cross the traffic marking; the other is that the space among the adjacent motor vehicle flows is available for bicycles to cross. With this observation, the probability of conflicts between motor vehicles and bicycles can be obtained as a product of their probabilities. Based on this probability, the result was summarized as follows: the probability for bicycles crossing the traffic marking obeys a negative exponential distribution, which is derived. The result was shown by theoretical analysis and was compared to actual survey data. The available probability for bicycles entering into motor vehicle flow was found by the use of a traffic survey. Therefore, a probability function was proposed with different spaces that led to a probability model for vehicle-bicycle conflicts. At last, using the survey data, the probability model proved to be correct.

Key Words: urban traffic; probability model; probability analysis; traveling of crossing traffic marking; vehicle and bicycle isolated by traffic marking

1 Introduction

It is common practice for Chinese city streets to have traffic lines dividing motor vehicle traffic from bicycle traffic. When there is high traffic on these road segments, bicycles will often cross the traffic lines and travel into the motor vehicle lane in order to overtake other vehicles. This situation creates a traffic conflict between bicycles and motor vehicles. This phenomenon is known as "bicycle line-crossing behavior". This occurrence not only reduces the flow of traffic on roadways, but also poses a traffic safety risk.

Bicycle line-crossing behavior typically requires two preconditions. The first is the demand of bicycle riders themselves to engage in bicycle line-crossing behavior. The second is the existence of a gap in motor vehicle traffic for a certain distance such that it is easy for bicycles to overtake. Bicycle overtaking is the combination of these two situations, and these two situations occur in a probability-based procedure. Therefore, employing the methods of probability theory to research bicycle line-crossing behavior is suitable. However, researchers in both China and abroad have not done much research on this subject in present years. The main research findings that currently exist on the subject are the following: Chen Yongheng analyzed the speed characters under mixed traffic conditions by a field study in Shijiazhuang . This study found that a linear trend exists with the involvement of motor vehicle speed due to the number of bicycles [1]. Jia Shunping divided the influences into two states: friction and block interference, and the research, based on sample data, showed that the velocity distribution of vehicles has different characteristics under different interference states. Additionally, vehicle driving speeds are significantly different under the friction interference and block interference [2]. Cara Hamanna provided the results that investments in bicycle-specific pavement markings and signage were shown to be beneficial to traffic flow. Furthermore, the results suggested that they may also reduce the number of

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bicycle-motor vehicle crashes and subsequent injuries and fatalities [3]. Chen Jun researched the bicycle traffic conflict model on urban pedestrian-bicycle paths, and provided the mathematical model of bicycle crossing travel [4]. From the above research, it can be seen that the researchers studied the influence of motor vehicle flow caused by bicycle flow, but there was a lack of systematic analysis on the crossing travel of bicycles.

Based on the fact that the above mentioned research is insufficient, this paper attempts to propose a probability-based analytical model of bicycle line-crossing behavior using the analytical methods of probability theory.

2 A Probability analysis of the demand for bicycles to cross lanes

According to the research of literature [5], we can see that the breadth of expansion for bicycle traffic is directly proportional to the amount of traffic. From this, it can be concluded that the increase in probability that an individual bicycle will overtake a car by passing a line will also be directly proportional to the increase in traffic.

Setting a probability distribution function for the line-crossing behavior of bicycles $F(f)$, with the increase in bicycle traffic as Δf, the increase in probability of line-crossing behavior is valued as

$$P(x \le f + \Delta f \mid x \ge f) = k\Delta f + o(\Delta f) \tag{1}$$

where,

P: probability density function for the line-crossing behavior of bicycle traffic;

f: the amount of bicycle traffic;

k: parameter;

$o(\Delta f)$: the high order infinitesimal of Δf.

From the above equation it can be concluded

$$\begin{aligned} &P(x \le f + \Delta f \mid x \ge f) \\ &= P(x \ge f,\ x \le f + \Delta f) / P(x \ge f) \\ &= k\Delta f + o(\Delta f) \end{aligned} \tag{2}$$

that is

$$(F(f+\Delta f) - F(f))/(1 - F(f)) = k\Delta f + o(f) \tag{3}$$

After multiplying both sides by $(1-F(f))$, and then subtracting by Δf, it simplifies to

$$(F(f+\Delta f) - F(f)) / \Delta f = (1-F(f))k + (1-F(f))o(f)/\Delta f \tag{4}$$

Taking the limit of both sides as Δf approaches zero since $o(\Delta f)$ is the high order infinitesimal value of Δf gives

$$\mathrm{d}F(f)/\mathrm{d}f = (1-F(f))k \tag{5}$$

With the boundary condition of $F(0)=0$, and $F(\Delta f)-1 \le 0$ the above differential equation can be reduced to

$$F(f) = 1 - e^{-kf} \tag{6}$$

The above equation is a probability model of the demand for line-crossing behavior of bicycle traffic, and it follows a negative exponential distribution.

The next step of analysis shows that for the same amount of bicycle traffic, the probability of line-crossing behavior varies with different bicycle lane widths. In other words, the probability of bicycle line-crossing behavior is relatively low on wider road segments, and relatively higher on narrower segments. Therefore, by making the operation conversion on Eq. (6) the following equation is derived

$$F(p) = 1 - e^{-hp} \tag{7}$$

where,

$p = f/m$, ($\mathrm{bic/h \cdot m}$);

m: bicycle lane width, m;

h: undetermined parameter.

In this paper, we calculated the value of the parameter h through actual survey data. As for the survey methodology, we adopted the video statistical method. Surveying included; setting cameras in high buildings along the road, recording the proceeding situations of the bicycle traffic stream, taking the materials back to the laboratory, conducting the acquisition and statistical analysis of related data, and obtaining the probability characteristics of the line-crossing phenomenon of bicycles.

We selected six road sections in the center of Ningbo City including Cuibai Road, Fanjiang’an Road, and Cangsong Road, etc. Each road had different bicycle flow volume characteristics and diverse widths of bicycle lanes ranging from 2 to 4 meters. Due to lower motor vehicles flow volume on these roads, bicycles receive less restriction when they travel into motor vehicle lanes, meaning that bicycles could change their lanes freely. During our survey, we counted line-crossing driving when bicycles crossed the lines and traveled on the motor vehicle lanes whether they return to the bicycle lanes or not.

In this survey, we chose three periods of time including peak and off-peak hours of the six roads mentioned, and acquired the videos of their traffic situations. We obtained 16 sets of data and 15 were proven valid. The results are shown in Table 1.

After converting Eq. (7), the following equation is obtained

$$\ln\left(1 - F(p)\right) = -hp \tag{8}$$

Therefore, if p is taken as an independent variable, and $\ln\left(1-F(p)\right)$ as a dependent variable, the value of parameter h can be obtained through a linear regression. Thus, by using a linear regression on the data in Table 1, the following result in Fig. 1 can be obtained.