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Investigating factors affecting riders' behaviors of occupying motorized vehicle lanes on urban streets

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ABSTRACT

The violation activity of non-motorized vehicles riding in motorized vehicle lanes interferes roadway traffic serious, as it can not only seriously depreciate the efficiency of motorized vehicle traffic, but also raise possibility of triggering traffic accidents. The primary purpose of this study was to investigate intrinsic features of unlawful non-motorized vehicles' violation behaviors of riding on motorized vehicle lanes. The binary logistic regression model was proposed to find inherent reasons of triggering such misbehaviors. The misbehaviors of non-motorized vehicles (including regular bicycles, electric bicycles and human-powered tricycles) at seven sections, located at Hefei, China, were collected and studied. The experimental results indicate that male traffic participants exhibit higher rates of traffic violations than females, and rainy days shows higher misbehaviors than sunny and cloudy days. Another finding is that morning peak violation rate is higher than the evening peak and non-peak hours due to the fact people are in hurry for work. The traffic density of motorized vehicles and the traffic density of non-motorized vehicles strongly affect illegal occupancy behavior. The effect of dividing strip type and non-motorized vehicle type on lane illegal occupancy behavior are significant. We find that the average lane illegal occupancy rate of non-motorized vehicle is 36.1% which suggests that over one-third of non-motorized riders violate traffic rules. The findings of this study can help traffic authorities, road construction departments and traffic participants perform effective and efficient measurements to improve road traffic safety.

1. Introduction

With the growing demands of traffic, non-motorized vehicles take advantages of energy saving, environmental protection and lower consumption of road resources, thus gain more and more popularity from traffic participants and transportation authorities. Travelling with non-motorized vehicles is also considered as an effective measurement for mitigating traffic congestion and reducing air pollution emission. Thus, it is encouraged by many traffic management departments in the world. For instance, the US Department of Urban Planning has issued a number of policies on the purpose of promoting the usage of multi-purpose bike in the commute travel (CMAQ, 2010). The Chinese government strongly advocates the use of bicycles by the public (China Daily, 2006), and the newly emerging shared-bike (such as Mobike and OFO) modes are highly supported by both national and local traffic authorities. In the past decade, Australia and European countries have made big efforts to stimulate bike uses among public (Pucher et al., 2011a, b).

1.1. Non-motorized vehicle development

With significant increase of traffic demand, the shortage of roadways resources and the protection of the environment, travelling by bike has become popular in different cities around the world, and the increasing number of traffic participants has involved in travelling by bike. For instance, in the United States, the number of people travelling by bike in 2009 was twice as that of in 2000, while the bicycle-sharing trips reached 0.6% (Pucher et al., 2011a). Meanwhile, traveling with electrical bicycle becomes increasingly popular due to advantages of comfort and convenience. For example, the percentage of going out with electric bicycles has reached to 10% among all cycle trips (Twisk et al., 2013).

Similar to developed countries, the number of non-motorized vehicles in developing countries has also experienced tremendous growth in past 40 years. Non-motorized vehicles have become a popular travelling mode. For example, the number of bicycles in Bogota, the capital of Colombia, sharply increased from 5000 in 1974 to 400,000 in

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2005 (Pucher et al., 2010). To cope with the enormous growth in bicycle users, Bogota has extended another 268 km for bicycle lanes, which ranked as the fifth in bicycle lanes density in the world (Li, 2008).

China is the country with the largest number of bicycles in the world. In fact, the bicycles ownership in China in 2004 was more than 450 million (Zhou et al., 2007). To reduce environmental pollution and alleviate traffic congestion on roadways, the Chinese government introduced a series of policies to promote bicycle travel mode since 2006 (China Daily, 2006), and the bicycle travel accounted for 38% among all the travel modes (Zhang et al. (2010)). In many cities with large population in China, bicycle travel mode accounts for 50% among all the trips (Zhou et al., 2007). Moreover, over the past 10 years, the rapid increase of electric bicycles results in the fact that China has become the country with the largest number of electric bicycles in the world. In 2011, there were 120 million electric bicycles registered in China, accounting for 90% of the global electric bicycles. Today, China's electric bicycle ownership has reached 250 million, which is as twice as in 2011.

1.2. Non-motorized vehicle accidents and violations

As the number of non-motorized vehicles increases, cycling trips have become more complicated, and accidents involving non-motorized vehicles have increased significantly. Cyclists face greater dangers than motorists in accidents as they have less privileges during the trip. According to the traffic safety survey in China, more than 13,000 bicyclists were killed in traffic accidents, and 54,286 were seriously injured. The bicycle-involved accident accounts for 12.8% of the total number of fatal accidents and 11.3% of injuries. Similarly, the safety of electric bicyclists is becoming an increasing concern. In 2004, 589 electric bicyclists were killed, and 5295 were seriously injured. However, in 2007, the number of deaths increased to 2469, and the number of seriously injured was 16,468 (CRTASR, 2004, 2007). Although, the proportion of non-motorized vehicle accidents in China has declined in recent years, non-motorized vehicle safety has attracted much attention from governments and researchers due to the increase of non-motorized vehicles number and bicycle trips number.

According to accident analysis researches, non-motorized vehicle violations accounted for 60% of fatal non-motor vehicle accidents. Therefore, analyzing and studying the factors that influence riders' violation behaviors is of great significance for ensuring the safety of non-motorized vehicles. Wu set up video recorders at three signalized intersections in Beijing and analyzed cyclists' red-light behaviors through real-time video (Wu et al., 2012). The study found that 56% of non-motorized vehicles violate traffic rules, and the most common violation behavior is travelling through intersections during red lights period. More specifically, middle-aged and young people walk across red lights with a much higher possibility than the elderly. The longer time with waiting for the red light, the bicyclists are more likely to pass during the red-light time (Wu et al., 2012). Du conducted a 7-day observational study at 14 intersections in Suzhou, China to analyze behaviors of cyclists (Du et al. (2013)). The study found that the bicyclists riding passengers are more likely to go through the intersections during red-light period, and the bicyclists carrying oversized items are also likely violate traffic rule. The use of a helmet on sunny and cloudy days is significantly less frequent than that on rainy days, while helmet use among delivery staff is 4 times that of the average rider. Marilyn Johnson performed an online survey to analyze the reasons for red-light infringement among local cyclists (Johnson et al., 2013). The results showed that 37.3% of cyclists reported that they had gone through a signalized intersection during the red-light phase. In addition, males are more likely to offend the rule than females, while older cyclists are less likely to violate the regulations than younger ones. Cyclists who are used to running at red-light period are more prone to be involved in bicycle-vehicle crashes. Left-turn behaviors accounted for the highest incidence of red-light violation at 32%.The incidence of red-light passing through an intersection without a red-light detection device accounted for 24.2%. The rate of running at red light was 16.6% in the absence of traffic. Zhang et al. designed a red-light passing test with or without sunshields at two intersections in Hangzhou (Zhang and Wu (2013)) and found that sunshields play a significant role in reducing red-light misbehaviors by non-motorized vehicles during hot days.

Current researches focus on violation behaviors of non-motorized vehicles running red lights. A number of accident collection data suggests that a large portion of fatal non-motorized vehicle accidents are caused by non-motorized vehicle violations of occupying motorized vehicle lanes. Based on the statistics on the causes of bicycle accidents in Shanghai, China, the occupation of motorized vehicle lanes accounted for 17.4% of fatal accidents, which was preceded only by sudden sharp turns and negligence. The violation of occupying motorized vehicle lanes not only seriously affects the efficiency of motorized vehicle traffic, but also presents a potential of hurting road safety. Kroll found that variability of the traffic behavior of bicycles riding in motorized lanes has increased, and swerves and dangerous overtaking behaviors have happened with a larger possibility (Kroll and Ramey, 1977). Jilla studied the influence of non-motorized vehicle lanes on traffic flow. The results of the study revealed that when a motorized vehicle drives near non-motorized vehicles which that are riding in a non-motorized vehicle lane, the average speed of the motorized vehicle will decrease, and the position of the motorized vehicle in the motorized vehicle lane will be laterally offset (Jilla, 1974). Pan studied the effect of non-motorized transport on motorized vehicle speeds in China, built a linear relationship between motorized vehicle speeds and non-motorized traffic volumes. With increase in the number of non-motorized vehicles, the speed of motorized vehicles decreased significantly (Pan and Kerali, 1999). Obviously, these effects are prone to cause traffic accidents when non-motorized vehicles occupy the motorized vehicle lanes. Thus, fatal accidents caused by the lateral movements of non-motorized vehicles and speed differences between motorized vehicles and non-motorized vehicles will increase dramatically. However, there is less research focusing on the factors that influence non-motorized vehicle violations of occupying motorized vehicle lane. Therefore, this study used a synchronous video camera method to record traffic behaviors at seven representative sections of urban areas at Hefei, China, to explore the factors that influence lane illegal occupancy of non-motorized vehicle. These factors included road conditions, time of day, rider characteristics and natural conditions. In terms of road conditions, the road density for motorized and non-motorized vehicle lanes, the types of dividing strips between motorized vehicle lanes and non-motorized vehicle lanes are likely to affect the rider's road selection behavior. Additionally, according to Chinese traffic regulations, both electric bicycles and bicycles belong to the class of non-motorized vehicles. The riders traveling with the two types of bicycles should obey the same traffic rule. However, electric bicycles are more similar to motorized vehicles in terms of power, and they are more dangerous. Therefore, it is necessary to determine difference of the two types of vehicles. Human-powered tricycles in China were also selected as a research object in this study. We would like to analyze the differences in illegal occupancy behavior between the three types of non-motorized vehicles. In summary, the purpose of this study was to identify and analyze the factors that affect the occupation motorized vehicles lanes by non-motorized vehicles. The results of the study can provide the useful data and measurements for road planning and construction department, traffic regulation authorities.

2. Method

Compared with questionnaires, video processing-based techniques records the behavioral characteristics of riders in their natural state, thus guarantees the true features of cyclist behaviors. Additionally, the recorded videos can be replayed for data checking, thus can ensure the accuracy of the traffic data. Based on the two advantages, video processing-based techniques become the mainstream method for studying the behavior of cyclists (Tiwari et al., 2007; Johnson et al., 2011; Pai et al. (2013)).

2.1. Observation point selection

The observation point of this study was selected in Hefei, which is the largest city in Anhui Province and is located in the central east of China. Hefei has a large number of bicycles and delivers a large number of shared bicycles in 2016. In addition, by the end of 2017, the number of shared bicycles in Hefei reached over 200,000. Furthermore, the number of registered electric bicycles in Hefei in 2016 was 480,000, and the total number of electric bicycles was as high as 1 million.

To ensure the generality and abundance of sampling, the following criteria were applied when selecting the observation points for study: (1) The observation points have diverse non-motorized traffic densities; (2) The investigation points have specialized non-motorized vehicle lanes; (3) There are no roadside parking spaces, no roadside bus stations and no temporarily parking in the non-motorized vehicle lane; (4) The universality of the observation points, the diversity of the type of dividing strips and the location of the road sections are also required. After the selection, seven typical section were carefully selected to conduct the investigation(Fig. 1). Table 1 summarizes the road geometry conditions of the 7 observation points.

2.2. Video data acquisition and record

A Sony FDR-AX30 camera was used to record behaviors of the non-motorized vehicles. The camera was placed in the observation section and concealed with covers. In that way, the camera can hardly be found by nearby bicyclists, and thus ensure that the recording were of natural riding behavior. The video recording time was randomly selected for 10 days over a total of 15 days from June 25 to July 9, including both weekdays and weekends. The daily recording time intervals include the morning peak (7:30–8:30), off-peak (14:00–15:00), evening peak (17:00–18:00) periods. The weather in the selected 10 days involved sunny, cloudy and rainy conditions.

We enlisted the help of three professional personnel for information identification and recording. Thirty videos in total were recorded. The three scorers were trained for identifying information before making video recordings. The training procedure involved identifying different road segregation measures, recognizing occupational distribution staff (Occupational distribution staff: see Fig.2), determining whether non-motorized vehicles occupied the motorway (Illegal occupying: see Fig.3), learning how to quickly and accurately identify riders' information to ensure the uniformity of data records. Each video was checked by 2 information recorders to ensure the accuracy of the data records. The influencing factors of non-motorized vehicle illegal occupancy behaviors in this study included gender, weather, time of day, traffic density (motorized vehicles, non-motorized vehicles), type of dividing strip, type of non-motorized vehicle, working days, professional delivery staff and whether the observation points were adjacent to an intersection. The types of dividing strip included landscaped dividing strips, device dividing strips and marking dividing strips. In addition to bicycles and electric bicycles, the non-motorized vehicles include human-powered tricycles with characteristics specific to China (Primary types of non-motorized vehicle: see Fig.4). For the purpose of statistics, we use the average traffic density per minute as the traffic density at the sections away from the intersection. Traffic density was divided into three levels which are: low (Motorized vehicle: 0–28 vehicle / lane * km; Non-motorized vehicle: 0–9.3 bicycle / m^2 * 100), medium (Motorized vehicle: 28–67 vehicle / lane * km; Non-motorized vehicle: 9.3–33.3 bicycle / m^2 * 100) and high (Motorized vehicle: >67 vehicle / lane * km; Non-motorized vehicle: >33.3 / m^2 * 100). According to design manual of Planning of Intersections on Urban Roads in China (National Standards of the People's Republic of China (2011)), we selected the position 30 m behind the parking line as the observation point which is adjacent to the intersection. Since the observation points are 30 m behind the stop line, the red light queue has less influence on the density change, so the traffic density of the sections adjacent to the intersection are not significantly different between the red light period and the green light period.

2.3. Data analysis

The phenomenon of non-motorized vehicles illegal occupying is affected by many complex factors. The dependent variable whether non-motorized vehicles occupied the motorway is a two classification-variable. Therefore, it is impossible to analyze with multiple linear regression. Logistic regression is a probabilistic nonlinear regression model, which is a multivariate analysis method for studying the relationship between classification observation results (dependent variables) and influencing factors (independent variables). Considering the

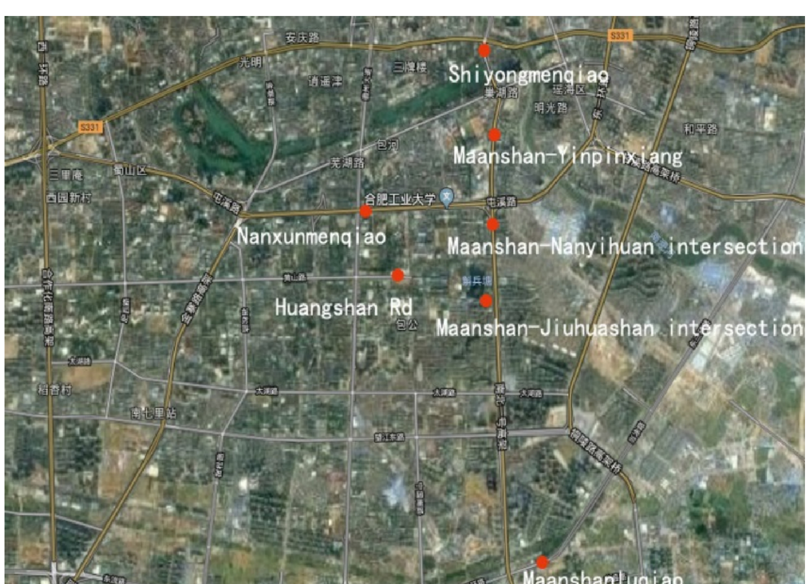

Fig. 1. Field survey locations.

Table 1
Road geometry at the observation points.

	Number of motorized lanes (both directions)	Motorway width (m)	Non-motorized vehicle lane width (m)	Dividing strip types	Whether adjacent to the intersection
Eastbound side of intersection of Nanxunmenqiao	4	3.5	3.5	Device	Yes
Eastbound side of Huangshan Road	3	4	4	Landscaped	No
Eastbound side of Maanshanluqiao	4	3.5	3.5	Marking	No
Southbound side of Maanshan-Nanyihuan intersection	3	4	3.5	Landscaped	No
Northbound side of Maanshan-Jiuhuashan intersection	5	3.5	3.5	Landscaped	Yes
Northbound side of Shiyongmenqiao	6	3.5	3.5	Marking	Yes
Southbound side of Maanshan-Yinpinxiang	3	4	3.5	Marking	No

Fig. 2. Occupational distribution staff.

dependent variable is two classification variable, we used a binary logistic regression model for data analysis.

This study recorded the behaviors and characteristics of a total of 12,327 riders' and quantified them for data for analysis. A binary logistic regression model was used to analyze the factors that affected violation based on the parameters of the violation rate, the coefficient value, the OR value and the 95% confidence interval. The first step in the data analysis was to determine non-motorized vehicles occupation behavior the motorway. A non-motorized vehicle crossing or touching a dividing line regardless of duration was defined as non-motorized vehicle illegal occupancy. Illegal occupancy was taken as the dependent variable. Gender, weather, time of day, traffic density, dividing strip type, non-motorized vehicle type, factors of working day, riders were occupational distribution staff, the riders near to an intersection were taken as the covariates. The coefficient value was analyzed for a positive or negative correlation with illegal occupancy. The OR value was used to analyze the effect of this factor on illegal occupancy behaviors.

We set the dependent variable as a rider occupying a motorway in violation, denoted as y_i, which is classified into two categories. The first category was illegal occupancy, which indicated that a rider occupied a motorway; that is, when the i_{th} rider rode on a motorway, $y_i = 1$. The second category involved a rider occupying a non-motorized vehicle lane; that is, when the i_{th} rider was riding in a non-motorized vehicle lane, $y_i = 0$. There are m factors that affect the dependent variable y_i, and they are denoted as independent variables $x_1, x_2,.., x_m$. According to the logistic model principle, the probability that the i_{th} rider occupying the motorized vehicle lane is as follows: $P_i = P(y_i = 1 | x_1, x_2, ...x_m) = \frac{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m)}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_m x_m)}$ where β_0 is a

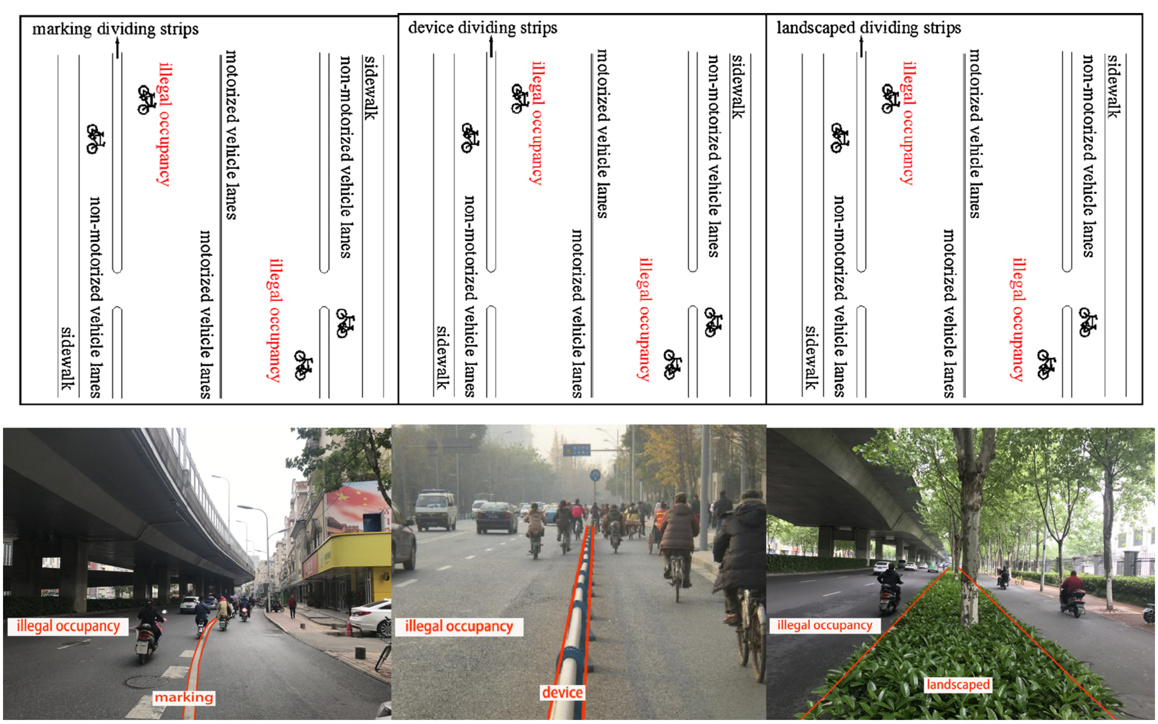

Fig. 3. Determining non-motorized vehicles occupation on the motorized vehicle lanes (the most left figure illustrates illegal occupancy behaviors).

Fig. 4. Primary types of non-motorized vehicles, bicycle (left), electric bicycle (middle) and human-powered tricycle (right).

Table 2
Rider illegal occupancy statistics.

Factor (Variable)	Classification	Value	Frequency	Percentage	The number of illegal occupancy	The percentage of illegal occupancy
Gender(x_1)	Male	0	7906	64.1%	3209	40.6%
	Female	1	4421	35.9%	1239	28.0%
Occupation(x_2)	Yes	0	210	1.7%	127	60.5%
	No	1	12117	98.3%	4321	35.7%
Weather(x_3)	Sunny	0	8724	70.8%	2633	30.2%
	Cloudy	1	1391	11.3%	850	61.1%
	Rainy	2	2212	17.9%	965	43.6%
Weekday(x_4)	Yes	0	9009	73.1%	2990	33.2%
	No	1	3318	26.9%	1458	43.9%
Time of the day(x_5)	Morning peak	0	4471	36.3%	1548	34.6%
	Evening peak	1	4944	40.1%	1793	36.3%
	Off-peak	2	2912	23.6%	1107	38.0%
Types of dividing strip(x_6)	Landscaped	0	7513	60.9%	2196	29.2%
	Device	1	1145	9.3%	205	17.9%
	Marking	2	3669	29.8%	2047	55.8%
Adjacent to the intersection(x_7)	Yes	0	4081	33.1%	1189	29.1%
	No	1	8246	66.9%	3259	39.5%
Motorized vehicle traffic density(x_8)	Low	0	1739	14.1%	577	33.2%
	Medium	1	8016	65.0%	3182	39.7%
	High	2	2572	20.9%	689	26.8%
Non-motorized Traffic density(x_9)	Low	0	2769	22.5%	1207	43.6%
	Medium	1	8340	67.7%	2610	31.3%
	High	2	1218	9.9%	631	51.8%
Type of non-motorized vehicle(x_{10})	Bicycle	0	1411	11.4%	100	7.1%
	Electric bicycle	1	10148	82.3%	3894	38.4%
	Human-powered tricycle	2	768	6.2%	454	59.1%

constant term and $\beta_1 \sim \beta_m$ are the regression coefficients.

The probability of illegal occupying (dependent variable) as recorded as P_i, and the probability of no violation was recorded as $1\text{-}P_i$. By division, we can obtain the odds ratio: $O_{\text{odds}} = \frac{P_i}{1 - P_i}$. The odds ratio was used to determine the effects of the factors that influenced illegal occupancy behavior. The influencing factors and value analyzed in this study are presented in Table 2. Among the 10 influencing factors, except gender, occupation, weekend, adjacent to the intersection are two categorical variables and the remaining variables are multi-class variables. However, the specific assignment does not represent the actual value, so the transformation should be performed according to the dummy variable. If there were k categories of dummy variables, the dummy variables were converted to k-1 variables.

3. Modeling results

3.1. Descriptive statistics

The total illegal occupying rate in this study was 36.1%.As presented in Table 2, the study population consisted of approximately 64.1% male (n = 7906) and 35.9% female (n = 4421). Moreover, the male rate of violation (40.6%) was significantly higher than the female rate (28.0%) (Table 2). Professional delivery personnel exhibited a violation rate of 60.5%, which was nearly double that of the non-professional personnel, 35.7% (Table 2). The violation rate on cloudy days reached 61.1%, twice the violation rate on sunny days, 30.2% (Table 2). The violation rate of 43.9% on weekends was higher than the violation rate of 33.2% on weekdays (Table 2). Based on the initial description of the percentages, the effect of the time of day was not significant. The incidence of illegal occupancy in the presence of a marking dividing strip was 55.8%, which was far higher than the rates of 29.2% and 17.9% for a landscaped dividing strip alone and a device dividing strip alone, respectively (Table 2).

3.2. Logistic regression analysis

As presented in Table 3, males exhibited a higher incidence of illegal occupancy behaviors than females (adjusted OR: 1.787; 95%CI: 1.634–1.955). Occupational delivery personnel exhibited a higher probability of illegal occupancy (adjusted OR: 2.269; 95%CI: 1.680–3.065) that was approximately 2.269 times that of the average rider (Table 3). Regarding weather conditions, sunny days were associated with the lowest rate of violation, which was 38.1% of what occurred on rainy days (adjusted OR: 0.381; 95% CI: 0.320–0.453) (Table 3). The rate of violations on cloudy days was 0.566 times that on rainy days (adjusted OR: 0.566; 95% CI: 0.453 - 0.708) (Table 3). During the morning peak, the probability of violation was the highest. The adjusted OR of the morning peak was 1.680 times that of the off-peak probability (adjusted OR: 1.680; 95% CI: 1.450–1.947) (Table 3). The type of dividing strip had a tremendous effect on riders' violation behavior. Riders on roads with a marking dividing strip were most prone to riding on the motorway. The adjusted OR of landscaped dividing strips was 0.196 times that of marking dividing strips (adjusted OR: 0.196; 95% CI: 0.170–0.226) (Table 3). The adjusted OR of device

Table 3
Logistic regression analysis results.

Factor	Classification	B	SE	Adjusted odds ratio (95%CI)
Gender	Male	0.581	0.046	1.787 (1.634–1.955)
	Female			
Occupation	Yes	0.819	0.153	2.269 (1.680–3.065)
	No			
Weather	Sunny	−0.966	0.089	0.381 (0.320–0.453)
	Cloudy	−0.569	0.114	0.566 (0.453–0.708)
	Rainy			
Time of the day	Morning peak	0.519	0.075	1.680 (1.450–1.947)
	Evening peak	0.095	0.073	1.099 (0.953–1.268)
	No-peak			
Types of dividing strip	Landscaped	−1.629	0.073	0.196 (0.170–0.226)
	Device	−1.652	0.121	0.192 (0.151–0.243)
	Marking			
Adjacent to the intersection	Yes	0.244	0.074	1.276 (1.105–1.474)
	No			
Motorized vehicle traffic density	Low	1.377	0.119	3.964 (3.139–5.004)
	Medium	0.954	0.087	2.596 (2.189–3.080)
	High			
Non-motorized traffic density	Low	−0.247	0.122	0.781 (0.615–0.992)
	Medium	−0.721	0.104	0.486 (0.397–0.596)
	High			
Types of non-motor vehicle	Bicycle	−2.843	0.134	0.058 (0.045–0.076)
	Electric bicycle	−0.729	0.084	0.482 (0.409–0.568)
	Human-powered tricycle			

dividing strips was 0.192 times that of marking dividing strips (adjusted OR: 0.192; 95% CI: 0.151–0.243) (Table 3). The adjusted OR of adjacent intersection sections was 1.276 times that of the ordinary sections (adjusted OR: 1.276; 95% CI: 1.105–1.474). As the traffic density of motorized vehicles increased, the incidence of illegal occupancy decreased. The adjusted OR of at a low density of motorized vehicles was 3.964 times that of conditions of high density motorized vehicles (adjusted OR: 3.964; 95% CI: 3.139–5.004) (Table 3). The adjusted OR of for conditions of medium density of motorized vehicles was 2.596 times that of the conditions of high density motorized vehicles (adjusted OR: 2.596; 95% CI: 2.189–3.080) (Table 3). The adjusted OR for conditions of low density non-motorized vehicles was 0.781 times that of a high density of non-motorized vehicles (adjusted OR: 0.781; 95% CI: 0.615 – 0.992) (Table 3). The adjusted OR of a medium density of non-motorized vehicles was 0.486 times that of the conditions of high density non-motorized vehicles (adjusted OR: 0.486; 95% CI: 0.397 – 0.596) (Table 3). Non-motorized vehicle type had a tremendous effect on riders' illegal occupying behaviors. The rate of illegal occupying of human-powered tricycles was the highest. The adjusted OR of bicycles was 0.058 times that of human-powered tricycles, while the adjusted OR of electric bicycles was 0.482 times that of human-powered tricycles.

4. Discussion

In this study, a video detection method was adopted to record riders' occupations of motorized vehicle lanes in a natural state. Through classification and analysis, we determined riders' violation behaviors under the effects of different factors. A binary logistic regression model was used to analyze the factors that influenced the riders' illegal occupancy behaviors.

The finding that males were more likely to engage in illegal occupying behavior than females is similar to the results of Yao, who conducted a self-assessment study on 603 electric bike riders in Beijing. The finding is also similar to the results of Chaney, who examined urban bike behavior in the United States (Yao and Wu, 2012; Chaney and Payne (2017)). The result is also similar to the findings of Marilyn Johnson in Australia and Wu in Hangzhou, who observed that males are more likely than females to run a red light (Wu et al., 2011; Johnson et al., 2013). Thus, men are more likely to attempt dangerous behaviors than women, and women are more concerned about how to circumvent danger and focus on self-protection measures.

Another finding of this study is that the rate of illegal occupancy decreased as the density of motorized vehicles increased. The violation rate for low density motorized vehicle conditions was nearly 4 times that of a high density of motorized vehicles. This result is similar to that of Chaney for the United States (Chaney and Payne (2017)). As the number of motorized vehicles increases and their density increases, riders prefer to choose safe riding behaviors and avoid dangerous behaviors. Moreover, we found that the violation rate in high density non-motorized vehicles was higher than the rates observed for medium and low densities of non-motorized vehicle conditions. This result may have been obtained because a high density of non-motorized vehicles will inevitably result in poor riding in non-motorized vehicle lanes and encourage riders to occupy motorways for smoother passage.

The results of the study regarding the effect of time of day show that the violation rate in the morning peak was higher than that the rates observed for the off-peak and evening peak, while the violation rate in the evening peak was not significantly different from that in the off-peak. The result is similar to that of Wei Du, who showed that the rate of violation was higher in the morning than in the afternoon (Du et al. (2013)). This discrepancy may be due to the higher volume of traffic during early peak hours; during this period, riders rush to work, non-motorized vehicle lanes become crowded, and tight time constraints make riders more likely to occupy motorized lanes. During evening peak and off-peak times, riders going home from work have no time constraints.

The results of this study regarding the effects of weather conditions indicate that the illegal occupying rate is higher on rainy days than on cloudy or sunny days. This finding is unlike the exist results of Wei Du, who found that the violation rate is higher on sunny days than on rainy days (Du et al. (2013)). This difference may be the reason that the rate of violation was related to the amount of rainfall. In the 15 recording days, the rain was light and intermittent. Compared with heavy rain, light rain does not pose a great threat to riders or induce self-protection or self-defense psychology and behavior; however, during rain, riders want to reach their destinations more quickly, causing them to occupy motorways in pursuit of shorter travel times. In addition, it was found that the violation rate of adjacent intersection sections was higher than that of ordinary sections. This difference may have been observed because intersections involve travel in many directions and may make it inconvenient to turn when traffic density is high in non-motorized vehicle lanes. Consequently, some riders tended to occupy motorized lanes. Additionally, the study found that violation rate of professional delivery staff was higher than that of ordinary riders. This result is similar to that reported by Wei Du (Du et al. (2013)). The discrepancy may be due to the limited delivery time of professional delivery staff and the economic benefits of high delivery volume coupled with high riding skill, which makes delivery riders even more likely to occupy a motorized vehicle lane when the non-motorized vehicle lane is crowded.

This study found that the type of non-motorized vehicle had a strong effect on riders' illegal occupancy. Human-powered tricycles were associated with the highest violation rate followed by electric bikes, and both of these violation rates were much higher than the rate for bikes. This finding is similar to that reported by Wu regarding riders’ red-light running behavior. Wu observed that electric bicycles run red lights more frequently than bicycles (Wu et al., 2011). This result may have been obtained because electric bikes are more similar to motorized vehicles than to bikes and because poor riding conditions on non-motorized vehicle lanes can encourage electric bike riders traveling at higher speeds to take over a motorway. The human-powered tricycle is widely used in China because of its excellent transportation capacity. However, due to its relatively large size, the tricycle is difficult to ride when the vehicle densities on the non-motorized vehicle lanes is high. Therefore, human-powered tricycle riders prefer to occupy the more spacious motorways. Furthermore, this study found that the illegal occupying rate on roads with a marking dividing strip is far higher than that of road sections with a landscaped dividing strip or a device dividing strip. This difference may be attributed to the fact that marking dividing strips have no physical barriers, unlike the other two types of divisions, allowing non-motorized vehicles to enter and leave a motorway at will, reducing lane boundaries and making it easier for riders to enter a motorway. These conditions also make it convenient for motorized vehicles to enter non-motorized vehicle lanes.

We found that the type of dividing strip and the type of non-motorized vehicle are the most significant factors. This study analyzed the influencing factors to enable effective and targeted traffic management of non-motorized vehicle illegal occupancy in China and other developing countries. We can take effective measurements after we learn that the group of riders and the road categories with high violation rates. For example, we find that the rate of violations of professional delivery staffs is much higher. We can set training courses for professional delivery staffs to achieve the goal of reducing the violation rate. Another example is that we should enhance traffic management a control in high non-motorized vehicle density sections near intersections. At the same time, this study provides a basis for urban road planning and construction to reduce non-motorized vehicle illegal occupancy. Sections with high volumes of non-motorized traffic should be provided with landscaped dividing strips or device dividing strips and ensure the proper width of non-motorized vehicle lanes to reduce non-motorized vehicle illegal occupancy as much as possible and ensure the safety and traffic efficiency of the roads.

5. Conclusion

This study recorded the behaviors and characteristics of a total of 12,327 riders and quantified them for analysis. A binary logistic regression model was used to analyze the factors that affected non-motorized vehicle illegal occupancy behaviors. The modeling results demonstrated that males were more likely to engage in illegal occupancy behaviors than females. The morning peak violation rate was higher than the off-peak and evening peak rates. The violation rate was higher on rainy days than on cloudy or sunny days. Riders near an intersection were prone to engage in illegal occupancy behavior. The violation rate of professional delivery staff was higher than other riders. Overall, non-motorized vehicle types impose significant effect on illegal occupancy. More specifically, human-powered tricycles exhibited the highest rate of violation, followed by electric bicycles and bicycles, bicycles exhibited the lowest rate of violation.

Though we have investigated non-motorized vehicles illegal occupancy behaviors, some further work can be done in the following aspects. First, the study sections locate on urban arterial roads in Hefei. Exploring non-motorized vehicles illegal occupancy behaviors at section locating on urban-rural roadways also deserves our focus. Second, the time period used in the study was in summer, while hot and humid weather may affect the riders' behavior. We will expand the scope of the research by finding features of cyclist behaviors at other seasons (such as winter and spring). Third, we did not consider the factors such as the riders’ income, education, or age, among others. Therefore, we cannot tell whether illegal occupancy behaviors are affected by these potentially influential factors, which will also be one of our further focus.

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