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# Built environment effects on bike crash frequency and risk in Beijing

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A B S T R A C T

Building a safe biking environment is crucial to encouraging bicycle use. In developed areas with higher density and more mixed land use, the built environment factors that pose a crash risk may vary. This study investigates the connection between biking risk factors and the compact built environment, using data for Beijing. In the context of China, this paper seeks to answer two research questions. First, what types of built environment factors are correlated with bike-automobile crash frequency and risk? Second, how do risk factors vary across different types of bikes? Poisson lognormal random effects models are employed to examine how land use and roadway design factors are associated with the bike-automobile crashes. The main findings are: (1) bike-automobile crashes are more likely to occur in densely developed areas, which is characterized by higher population density, more mixed land use, denser roads and junctions, and more parking lots; (2) areas with greater ground transit are correlated with more bike-automobile crashes and higher risks of involving in collisions; (3) the percentages of wider streets show negative associations with bike crash frequency; (4) built environment factors cannot help explain factors contributing to motorcycle-automobile crashes. In China's dense urban context, important policy implications for bicycle safety improvement drawn from this study include: prioritizing safety programs in urban centers, applying safety improvements to areas with more ground transit, placing bike-automobile crash countermeasures at road junctions, and improving bicycle safety on narrower streets.





## 1. Background

Concerns over safety are the strongest deterrents to new bicyclists, preventing future growth in bicyclist numbers (Racioppi, Eriksson, Tingvall, Villaveces, & Organization, 2004). Bicyclist fatalities and injuries cost society a lot. Therefore, issues related to bicycle safety have been intensely studied, particularly in the United States (US) and the European Union (EU). Many researchers are exploring the environmental and individual risk factors that contribute to the exposure and occurrence of crashes over the years. Many approaches for promoting safe biking have been proposed, including engineering, education, and enforcement strategies (TenBrink, McMunn, & Panken, 2009). However, due to the lack of accessible data, bicycle safety issues are rarely investigated in aggregated units and at a municipal level in China.

China has a long legacy of biking. Convenient, efficient, and affordable, biking is well suited for traveling short distances in dense urban environments. However, due to continued suburbanization and motorization, bike use is steadily decreasing in urban China. This decline spans three decades but China still had 0.551 billion bikes in operation in 2014 (News, 2014), accounting for roughly 1/3 of all bikes worldwide (Wang & Jiang, 2003). Different from the US and the EU, bike use in China is characterized by its typological diversity, including conventional bikes (bicycle & tricycle), electrical pedal bikes (e-bike), and motorized bikes (motorcycle). Compared to traditional bicycles, the number of e-bikes are increasing in recent years due to their greater mobility. In 2011, the number of e-bikes reached 0.12 billion, accounting for 1/4 of all China's bikes (Du et al., 2014). Motorcycle sales reached 13,728,000 units in the first 10 months of 2016, despite the restrictions placed on motorcycle usage in many major cities (China Association of Automobile Manufacturers, 2016). A particularly exciting development is the birth of mobile bike (Mobike), also known as an 'uber-bike', which is a type of public bike without a dock. At the end of 2016, Mobike was launched in Shanghai, and then quickly expanded to other major Chinese cities. To hitch a ride, a Mobike user launches the app on a personal smartphone and scans the QR code on the bike, which unlocks the bike's smart lock and times the duration of the ride. A user can park a Mobike at any destination, leaving it for the next rider. In 2017, 30 million

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Mobikes become available, with the intent of facilitating first/last-mile connectivity. So, while biking in China is shrinking overall, it is also experiencing a large-scale renaissance.

Unfortunately, due to continued economic growth, dispersed land use (Yang, Shen, Shen, & He, 2012), and prevailing social attitudes regarding pride in car ownership (Chen & Zhao, 2013), urban development in China is characterized as auto-oriented and transit-oriented, meaning it is no longer bicyclist-friendly. For example, in Beijing, most municipal transportation funding was assigned to highway and railway construction, and the bicycle mode share decreased steadily from 57% in 1990 to 38% in 2000 and to 16% in 2010 (walking is excluded) (Lusk, 2012; Transportation Commission of Beijing Municipality, 2012). Also, apart from an unfriendly biking environment, the popularity of e-bikes results in higher crash rates (Wu, Yao, & Zhang, 2012; Yao & Wu, 2012). While the total number of traffic fatalities is continuing to decrease in China, collisions involving e-bikes are growing tremendously (Wu et al., 2012; Yao & Wu, 2012). By 2006, the percentage of traffic fatalities in motorcycles in China was 28.1%, which was twice the number of other non-motorized vehicles (WorldBank, 2008).

The management and planning for biking in China face a gap between demand and supply. Bicycling demand in major cities has been revitalized, driven by increasing concerns about road congestion. Local agencies have used travel demand management tools, such as license auction and tolling, to discourage driving in metropolitan areas, which indirectly contributes to the growth in the bicyclist population. However, major cities are undergoing rapid urbanization and motorization as central cities merge with neighboring towns to enlarge geographical scopes to host immigrants (Cervero & Day, 2008; Pan, Shen, & Liu, 2011; Pucher, Peng, Mittal, Zhu, & Korattyswaroopam, 2007; Yang et al., 2012). Consequently, the quality of bicycle facilities varies spatially. In suburban areas, bike paths are commonly interfered by road traffic, occupied by illegal parking, and poorly-maintained. Also, due to their greater mobility, e-bikes are becoming indispensable for many low-income individuals, which poses threats to bicyclists when they share a bike path.

Overall, it is encouraging to observe the regained popularity of biking, but cities in China still face many challenges in maintaining safe biking environments. This study investigates how land use and road design factors contribute to bike-automobile crashes, comparing the proposed risk to the actual frequency of crashes. Three types of bikes are investigated in this study, including conventional bikes (bicycle & tricycle), electrical pedal bikes (e-bike), and motorized bikes (motorcycle). The objectives include: (1) to understanding the different levels of risk for different types of bikes; (2) to shed light on road infrastructure development leading to a safer biking environment.

## 2. Literature review

### 2.1. Bicycle crash frequency and the built environment

To identify built environment risk factors for biking, bicycle crash frequency and its determinants have been widely examined. Since many studies have already undertaken comprehensive literature reviews (Chen, 2015; Narayanamoorthy, Paleti, & Bhat, 2013; Wei & Lovegrove, 2012), this study only focuses on the recent research that has been published after 2010. Among the number of area-based research correlating bicycle crash frequency with the built environment, most of them have used traffic analysis zone (TAZ) as the analytical unit (Cai, Lee, Eluru, & Abdel-Aty, 2016; Chen, 2015; Narayanamoorthy et al., 2013; Siddiqui, Abdel-Aty, & Choi, 2012; Wei & Lovegrove, 2012).

Findings from previous research suggest positive relationships between population density or employment density with bicycle crash frequency (Siddiqui et al., 2012; Wang, Huang, & Zeng, 2017). As for road type, local streets are safer than arterial routes for biking, and this conclusion is indicated by different variables, such as the length of bike lanes on arterial routes versus on local streets (Chen, 2015), the arterial-local street intersection percentages and the length of lanes versus bike lanes (Wei & Lovegrove, 2012). Different types of intersections also show various effects on bicycle crash frequency. Generally, bicycle crashes are more likely to happen at complicated intersections with more legs (Chen, 2015; Wang et al., 2017). In terms of roadway design factors, a consistent finding based on existing studies is that the number of intersections and the number of signals are both positively associated with bicycle crash frequency (Chen, 2015; Wang et al., 2017; Wei & Lovegrove, 2012). Bike lane type is a key measurement of bicycle safety, cycle tracks (dedicated bike lanes) and separated or buffed bike lanes are generally much safer than other bicycle facilities (Narayanamoorthy et al., 2013; Reynolds, Harris, Teschke, Cripton, & Winters, 2009). In addition to the above, the number of bus stops is positively associated with bicycle crash frequency (Wei & Lovegrove, 2012).

The relationship between traffic volume and bicycle crash frequency is relatively inconsistent in the prior literature. Two studies suggest a negative association between traffic volume and bicycle crash frequency (Chen, 2015; Wei & Lovegrove, 2012), while a recent study indicates a positive association between traffic volume on major arterial routes and bicycle crash frequency, and an insignificant association between traffic volume on minor material routes and bicycle crash frequency (Cai et al., 2016). This inconsistency is potentially explained by the theory of 'safety in numbers' (Bhatia & Wier, 2011; Jacobsen, 2003) that there is a nonlinear relationship between traffic volume and bicycle crashes.

Road speed limit is an important traffic control measurement in explaining bicycle crash frequency. Chen (2015) has suggested that zonal-average speed limit is positively associated with bicycle crash frequency. Similarly, Siddiqui et al. (2012) have found that bicycle crashes are positively correlated with the length of highways (speed limit >35 mph).

Land uses represent different human activities, and the effects between land uses and bicycle crash frequency vary in the prior literature. A study suggests that commercial and industrial land uses are associated with more non-incapacitating cyclist injuries (Narayanamoorthy et al., 2013), but these percentages are not significant predictors of bicycle crashes in the other two studies (Chen, 2015; Strauss, Miranda-Moreno, & Morency, 2013). In terms of location, distance to urban areas suggests a negative relationship with bicycle crash frequency, indicating that more bicycle crashes are occurring in urban settings (Cai et al., 2016).

### 2.2. Bicycle crash risk

Bicycle crash risk remains an under-investigated field due to the lack of appropriate exposure measurements. Several variables are candidate exposure measures, including bicycle miles traveled, bicycle hours traveled, bicycle volume, and bicyclist population (Chen, 2015). However, biking is historically considered as an unimportant transportation mode, and most local authorities generally do not initiate surveys to collect data to quantify these measures.

To obtain exposure measures, great endeavors have been placed on estimating bicycle volume through simulation or regression techniques by adjusting the effects of weather, time of a day, land use, and roadway design (Chen, Zhou, & Sun, 2017; El Esawey, Mosa, & Nasr, 2015; Fournier, Christofa, & Knodler, 2017b; Hankey et al., 2012; Hankey, Lindsey, & Marshall, 2014). With advancement in estimating the number of on-street bicycles, a deep input has been invested in estimating bicycle volume for approximating bicycle crash risk at intersections and road segments (Dozza, 2016; Fournier, Christofa, & Knodler, 2017a). It is worth mentioning that the calculated bicycle crash risk not only considers the bicycle traffic but also the vehicle traffic (Fournier et al., 2017a).

Yet, there are still many weaknesses in such studies. First, the predictions of bicycle volume are based on very limited data. For example, in



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