THE EVALUATION OF BICYCLE PATHS ON BRIDGES

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Abstract

Bicycle accidents have increasingly caused casualties and property damage. Many countries have therefore started to pay more attention to designing the space of bicycle paths. However, few studies have focused on the design of bicycle continuity between each bicycle path. In this study, the concept of using both spatial crash probability (P) and crash severity index (CSI) is introduced to address the bicycle safety issue on bridges in Central Business Districts (CBDs). Bicycle paths on bridges usually face design difficulties due to limited space, different altitudes and the amount of traffic volume. Therefore, a systematic process should be established to evaluate and implement cycling space on bridges. The characteristic of bicycle-motorized vehicle collisions (BMV), traffic engineering, road environment and driving behaviour are analysed through spatial negative binomial modelling (NB). It is the aim to give recommendations to city planners and governments concerning the enhancement of bicycle safety and riding continuity on bridges.

Keywords: bridge, continuity, bicycle paths design, spatial negative binomial modelling (NB), crash severity index (CSI), bicycle-motorized vehicle collisions (BMV), and geographic information system (GIS)

1 Introduction

Bicycle accidents have increasingly caused casualties and property damage. Many countries have started to pay more attention to the prevention of bicycle-motorized vehicle collisions (BMV). However, previously little research involved cycling traffic engineering due to insufficient on-road cycling monitoring systems among many developed countries. Comparing Taiwanese bicycle fatalities with other developed countries in 2013, the number of bicycle fatalities per million inhabitants was at 5.60% (NPA), that of the European Union (EU) was at 7.86% (ERSO), and that of the United States (US) was at 2.35% (NHTSA). The daily cycling usage rate in Taiwan was at 11.5% on average, that of the EU at 15.6%, and that of the US was at merely 0.4%. As can be seen, Taiwan has a relatively higher bicycle fatality rate compared with other developed countries. Thus, improving bicycle safety is a crucial issue in Taiwan. This research focuses on how to address the limited cycling space on bridges for urban commuting purposes, through traffic engineering design, with the aim to reduce and prevent the BMV collisions. In the Taipei metropolis, bridges had higher bicycle collision and injury severity rates than other roads. So far, few studies have given exact values about the way in which traffic engineering factors affect BMV accident frequencies and injury severities. Therefore, a spatial-GIS combined with temporal-probability modelling was established to understand the spatial and temporal patterns of BMV collisions on bridges, to evaluate bicycle spaces on bridges, and to make recommendations for cyclists and urban planners to enhance bicycle safety.

2 Data collection and processing

Establishing bicycle accident modelling involves a series of investigation steps, including: accident data collection, potential risk factor analysis, and the division between road segments and junctions. Additionally, the data processing procedure was divided into three steps: the first step was to obtain all bicycle collision data located in the Taipei metropolis between 2011 and 2013 from the Taiwan National Police Agency (NPA); the second step was to pinpoint bicycle black spots by recognizing their road environmental features from police accident reports, annual orthophotos and field investigation, Figure 1. The black spots were pinpointed by using GIS spatial clusters though kernel density estimation methods (Levine et al., 1995; Kim et al., 1995; NCCGIA, 2000; Schneider et al., 2002); the third step is to construct bicycle collision networks of the whole Taipei metropolis, to distinguish road segments and junctions from these networks, and to develop a BMV collision frequency and severity database.

An overview of the origin of all data sources considered is shown in Figure 2. As can be seen, the bicycle accident database in this research was developed because of the need to include the road environment of bicycle incident sites. The large amount of black spot data from the government institutions and our own field investigation was categorized into different road environment conditions. The categorization of the road environment consists of road environmental conditions, traffic engineering facilities and traffic control systems.

Although human factors and junctions were often considered as two of the main causes among most bicycle collisions, the location of bicycle incident sites may in fact be highly related to the geometric design and road environment on bridges as well. Improperly designed road segments or junctions on bridges may easily become potential conflict areas and cause BMV accidents. This research also shows that more than triple the number of BMV clashes occurred on road segments in comparison with the junctions on bridges(216/284). If the government invariably looks at the responsibility of road users for bicycle accidents, rather than also taking into account the road environment, it will be inevitable that similar BMV accidents reoccur.

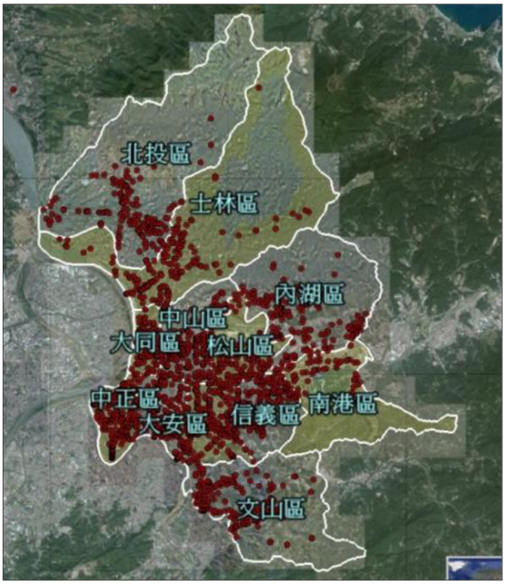


Figure 1 A three-year BMV collision database was created in this research. Each marked red point is a bicycle incident site located in the Taipei Metropolis between 2011 and 2013.

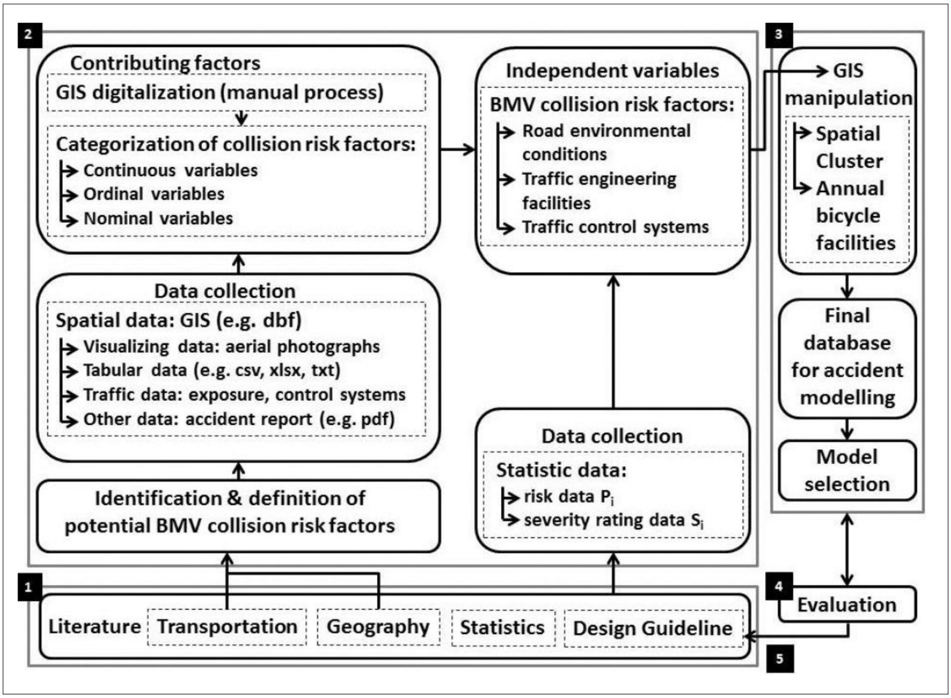
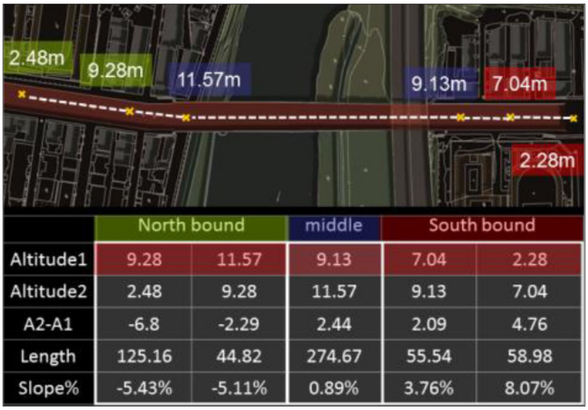


Figure 2 The Data collection and processing flow chart of bicycle collisions

The objective of this study is to understand the contributing factors between BMV collisions on bridges and road environment, geometric design, traffic engineering facilities, and traffic control facilities, and then to assess the level of impact of these factors on the reduction of the frequency and severity of BMV collisions on bridges. In order to understand the involved contributing factors of BMV accidents on bridges, the 41 factors being considered were divided into continuous variables, ordinal variables, and nominal variables. Some contributing factors were highly correlated, thus each pairs of dependent variables was first examined for its explanatory ability of the accident model, and the variables with less favourable explanation were then eliminated from the model.

3 Spatial negative binomial (NB) modelling

Firstly, each road was divided into several segments, Figure 3. Each junction collision site includes several forks, which are ten-meter buffers around each junction, Figure 4. For a given road segment or junction i, if the risk of involvement in bicycle accidents is P_i, then the number of bicycles may follow a binomial distribution, (Wang and Nihan, 2004) shown as Eqn (1). The probability with n_i bicycle accidents in the bridge segment or junction i is (1), where i is the section index; V_i is the traffic volume of section i; n_i is the number of bicycle accidents associated with motorized vehicles at specific V_i traffic volume; $P(n_i)$ is the probability with n_i bicycle accidents; P_i is the bicycle risk for motorized vehicles at V_i traffic volume. Comparing the bicycle risk P_i and traffic volume V_i, the value of P_i is very small since the number of bicycle accidents rarely exceeds the normal motorized vehicle volume. As a result, the Poisson regression model can explain the binomial distribution (Pitman, 1993) for bicycle accidents analysis and estimation. Moreover, Eqn (1) can be approximated by Eqn (2). The distribution parameter of the Poisson regression can then be presented in Eqn (3), where $E(n_i)$ is the expected value of n_i.



	North bound		middle	South bound	
Altitude1	9.28	11.57	9.13	7.04	2.28
Altitude2	2.48	9.28	11.57	9.13	7.04
A2-A1	-6.8	-2.29	2.44	2.09	4.76
Length	125.16	44.82	274.67	55.54	58.98
Slope%	-5.43%	-5.11%	0.89%	3.76%	8.07%

Figure 3 Each road divided into several sections, mutually corresponding to different geometric configurations of the road segment

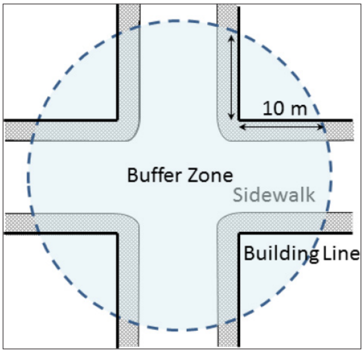


Figure 4 Definition of a junction: ten-meter buffers from the corner of building lines

$$P(n_i) = \binom{V_i}{n_i} P_i^{n_i} (1 - P_i)^{V_i - n_i} \tag{1}$$

$$P(n_i) = \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!} \tag{2}$$

$$\mu_i = E(n_i) = V_i P_i \tag{3}$$

$$\ln \mu_i = \ln(V_i P_i) + \varepsilon_i \tag{4}$$

$$P(n_i \mid \varepsilon_i) = \frac{\left(V_i P_i e^{\varepsilon_i}\right)^{n_i} e^{-V_i P_i e^{\varepsilon_i}}}{n_i!} \tag{5}$$

$$P(n_i \mid \varepsilon_i) = \frac{\prod(n_i + \theta)}{\prod(n_i + 1) \prod(\theta)} \left(\frac{\theta}{V_i P_i + \theta}\right)^{\theta} \left(\frac{V_i P_i}{V_i P_i + \theta}\right)^{n_i} \tag{6}$$

$$V(n_i) = E(n_i) = \left[1 + \delta E(n_i)\right] \tag{7}$$

$$P_i = \frac{F_i}{F_i + e^{-\beta_i X_i}} \tag{8}$$

$$S(n_i) = \binom{V_i}{n_i} S_i^{n_i} \left(1 - S_i\right)^{V_i - n_i} \tag{9}$$

$$S_i = P_i\left(EPDO\right)_i = P_{iA_3} + 27.8P_{iA_2} + 45.9P_{iA_1} \tag{10}$$

A Poisson regression with non-negative, discrete and random properties is often applied to accident prediction. However, this regression method requires that the Poisson distribution's expected value (mean value) is equal to its variance. In many cases, as with this study, the Poisson model is considerably restricted by this constraint, because the accident data have to be over-dispersed to match this constraint. By changing Eqn (3) into the log transformation, adding an independent distribution error εi in Eqn (3), Eqn (4) can be shown as follows: Next, e^{ε_i} is assumed to follow a Gamma distribution, i.e. equal to 1, variance given to δ, and $\theta = 1/\delta$. Furthermore, putting Eqn (4) into Eqn (2) can be presented as Eqn (5), and a negative binomial regression model can be derived as Eqn (6). Thus, the expected values of the NB and the Poisson regression model still remain the same, and its variance is shown in Eqn (7). The NB distribution will be adopted in this bicycle accident model, if θ is at a significant level. Otherwise, the Poisson distribution will be more suitable than the NB distribution. P_i, the bicycle accident risk for an assumed bicycle volume F_i and a series of explanatory factors, can be shown as Eqn (8). F_i is based on the estimation of cycling population of this area by field investigating the number of bicycle riders. β_i is a set of coefficients, and X_i is a set of contributing factors in section i.

This model has three advantages. Firstly, the bicycle accident risk approximates 0 where there is little bicycle volume at the junctions or the road segments. Secondly, β_i indicates an increasing or decreasing effect on the bicycle accident risk Finally, the severity ranking procedure was developed to assess the severity of each accident location by following two fundamental methodologies. $S(n_i)$ is the severity probability with n_i bicycle accidents, introduced as Eqn (9) into the original NB modelling to replace P_i. The severity S_i finally can be derived as Eqn (10) and P_{iA1}, P_{iA2}, P_{iA3} are the respective bicycle risk based on the accident severity for motorized vehicles at V_i traffic volume.

Table 1 Contributing factors with continuous variables, listed significant only.

Contributing factors	mean	Standard deviation	Minimum	Maximum
speed limit X_{i3} (km/hr.)	52.48	9.226	20	70
daily bicycle volume F_i (in 1000)	0.393	0.589	0.048	5.891
daily traffic volume X_{i5} (in 1000)	18.566	9.446	14.066	139.962
numbers of lanes (unidirectional) X_{i34}	2.9200	1.43	1	9
width of sidewalk X_{i35} (m)	1.29	1.64	0	10.22
width of the lane at the accident location X_{i36} (m)	3.50	2.72	0	34.00
areas of a junction X_{i37} (in 100 m^2)	3.0604	6.7928	0	39.76

Table 2 Contributing factors with ordinal variables, listed significant only.

road environmental conditions	**the value and frequency of observed variables**				
	0	1	2	3	4
speed limit X_{i3}	19(6.7)	5(1.8)	77(27.1)	183(64.4)	0(0.0)
traffic engineering facilities	**the value and frequency of observed variables**				
	0	1	2	3	4
lane types X_{i15}	114(40.1)	6(2.1)	22(7.7)	54(19.0)	88(31.0)
obstacles X_{i22}	264(93.0)	20(7.0)			
bidirectional overtaking-prohibited marking X_{i25}	238(83.8)	23(8.1)	23(8.1)		
unidirectional overtaking-prohibited marking X_{i26}	280(98.6)	1(0.4)	3(1.4)		
divisional facilities X_{i28}	53(18.7)	231(81.3)			
lane changing-prohibited facilities X_{i30}	270(95.1)	10(3.5)	4(1.4)		
traffic control systems	**the value and frequency of observed variables**				
	0	1	2	3	4
signalized facilities X_{i38}	203(71.5)	9(3.2)	40(14.1)	32(11.3)	
timing (sec) X_{i40}	873(42.7)	618(30.2)	553(27.1)		

Table 3 The correlation test of contributing factors, listed significant only

Contributing factor	**Variables (eliminated)**	**Correlation**
lane types X_{i15}	priority lanes Xi16	0.766
signalized facilities X_{i38}	the condition of signalized facilities Xi39	0.782
timing (sec) X_{i40}	signal phase X_{i41}	0.869

4 Results

In this spatial bicycle accident model, X_i is a set of contributing factors, which may affect the accident risk and severity on bridges. By using the maximum likelihood estimation (MLE) approach, estimated coefficients (β_i) of these factors can be obtained. After running the estimated procedures through the software limdep 9.0, the spatial negative binomial modelling at the significance levels of 99.9% is superior to and therefore replaces the Poisson model. This result confirms that the spatial NB modelling is more suitable to assess the risks and severities of bicycle accidents in Taipei metropolis. Excluding collinear problems, 36 variables remain in the final risk model. The estimated coefficients and their significance levels (P-value) are presented in Table 5. The value of factors shows the comparative risk level of holistic NB modelling. It also shows that approximately one half of the contributing factors are significant in this model, giving a fitted classification under the model.

5 Discussions and recommendations

Evaluating accident risks with special-temporal methods is much more useful than those with conventional blind spot methods, since spatial NB modelling can calculate the potential accident risk at each location within the whole bridge road network. Based on traffic volume, lane types, and road pavement materials, accident risks can be estimated at those unreported locations. On the other hand, blind spot methods only provide the risk value of recorded locations, but cannot estimate possible existing risks of unrecorded locations of bicycle-motorized vehicle collisions. Moreover, blind spot methods do not take the construction period of transportation facilities into consideration (Vandenbulcke, Thomas et al., 2014). Some research locations were dangerous in the past, but during the research period, the transport facilities have already been implemented or changed. Blind spot methods also do not take periodic traffic volumes and directional traffic volumes into account. They usually indicate only bidirectional traffic volumes, and identify how it affects riding safety at both sides of the road. In fact, many blind spots were concentrated at one side of the road. Using blind spot methods may lead to misguided analysis and propose mistaken suggestions toward existing traffic facilities on bridges.

Table 4 The list of variables and contributing factors of spatial NB modelling, listed significant only

variables	**definition of categories**	**data source**	**references**
road networks		annual ArchGIS road networks from Department of Urdan Development,Taipei city Goverment	Haleem and Abdel-Aty, 2010
BMV accident in location i	i =1~4018, 284 samples are observed on bridges	annual collision site figures from Taipei Metropolis Police Department and Taiwan National Police Agency (NPA)	
frequencies of BMV accidents in location i	1~25	clusters though kernel density estimation methods, original datasets from annual collision site figures	Levine et al., 1995; Kim et al., 1995; NCCGIA, 2000; Schneider et al., 2002
The estimation of accident costs in the Taipei Metropolis	A1=568,413, A2=344,490, A3=12,384(USD)	Department of Transportation Taipei City Government (DOT), 2003 and 2015	Haleem and Abdel-Aty, 2010
annual GPD of Taiwan		annual GDP report from Statistics from Statistical Bureau, Taiwan	
crash severity index (CSI)	A1=fatality, A2=injury, A3=property damage	National Road Traffic Safety Commission (NRTSC)	Vorko-Jović et al., 2006; Daniels et al., 2009
daily bicycle volume F_i	48~5891	field investigation from this research, and road sensor data fromTaipei City Traffic Engineering Office	Wang and Nihan, 2004
contributing factors			
daily traffic volume X_{i5}	14066~139962	Road sensor data, from Taipei City Traffic Engineering Office	Sando et al., 2005; Daniels et al., 2009
speed limits (km/hr.) X_{i3}	20~70	tables from Taipei City Traffic Engineering Office Traffic Control Center	Räsänen et al., 1999; Wang and Nihan, 2004; Vorko-Jović et al., 2006; Abdel-Aty et al., 2007; Haleem and Abdel-Aty, 2010
minimum sight distance (m)	0=unlimited(>30), 1=16~30, 2=1~15m	annual collision site figures from Taipei Metropolis Police Department	Blomberg et al., 1986
width of the road (m) X_{i12}	10.2~44.5	annual datasets of facilities measured by AutoCAD software, which received from Ministry of the Interior in Taipei	Daniels et al., 2009
the number of road forks X_{i7}	0=road segment, 1=T-road with 3 forks, 2=intersection with 4 forks, 3=junction with 5 forks, 4= junction with more than 5 forks		Haleem and Abdel-Aty, 2010
lane types X_{i15}	0=no lane categories, 1=the accident occurred within the lane of fast transport modes, 2=of slow transport modes, 3=of mixed transport modes, 4=within the priority lane of curtain vehicles		Rodgers, 1997; Daniels et al., 2009

Table 4 The list of variables and contributing factors of spatial NB modelling, listed significant only (cont.)

variables	definition of categories	data source	references
Priority lanes X_{i16}	0=no priority lane, 1=lane exclusively for buses, 2=lane exclusively for scooters and motorcycles, 3=path for motorcycle priority		Rodgers, 1997; Räsänen et al., 1999; Abdel-Aty et al., 2007; Daniels et al., 2009
paving materials X_{i19}	0=no paving materials, 1=asphalt (soft pavement), 2=concrete with steels (rigid pavement) , 3=bricks with rigid pavement;		Haleem and Abdel-Aty, 2010
bidirectional overtaking-prohibited marking X_{i25}	0 = without marking, 1 = marking, 2= marking with protruding flickers on the ground		Blomberg et al., 1986
unidirectional overtaking-prohibited marking X_{i26}	0=without marking, 1=marking, 2=marking with protruding flickers on the ground		Blomberg et al., 1986
divisional facilities X_{i28}	0=no divisional facilities, otherwise=1		Daniels et al., 2009
lane changing-prohibited facilities X_{i30}	0=no, 1=the location with lane changing-prohibited marking, 2=the location with both lane changing marking-prohibited and physical facilities (e.g. protruding flickers on the ground)		
width of dividers for fast and slow traffic modes (m) X_{i31}			Daniels et al., 2009
slow lane marking			Hunter et al., 1997; Räsänen et al., 1999
curb marking			Hunter et al., 1997; Räsänen et al., 1999
number of lanes (unidirectional)			Sando et al., 2005; Abdel-Aty et al., 2007; Daniels et al., 2009
area of junctions (m^2)			
signalized facilities / the condition of signalized facilities	0=no, otherwise=1		Preusser et al., 1982; Hunter et al., 1997; Daniels et al., 2009
Timing (hr.) / signal phrase (sec) X_{i41}	0~24/ 0= 0~60, 1= 61~120, 2 = ›120 sec		Blomberg et al., 1986; Rodgers, 1997
maneuver of motorists	0=straight, 1=left-, 2=right-turning		Preusser et al., 1982; Daniels et al., 2009
maneuver of cyclists	0=straight, 1=left-, 2=right-turning		Räsänen et al., 1999; Daniels et al., 2009

Table 5 The result of spatial negative binomial modelling (grey = not significant)

risk of BMV accident	**frequencies**		**severity**	
spatial negative binomial modelling	**coefficient**	**P-value**	**coefficient**	**P-value**
consistent	-0.3531	0.8090	5.1253	0.0000**
road environmental conditions				
daily traffic volume (exposure)	0.0711	0.0560	0.4966	0.0640
speed limits (km/hr.)	-0.2031	0.0610	0.1141	0.0129*
minimum sight distance	0.4977	0.2014	0.4438	0.0007***
traffic engineering facilities				
lane types (priority lane)	0.2778	0.0000***	0.3196	0.0000***
paving materials	-0.7736	0.0315*	-0.7611	0.1425
bidirectional overtaking-prohibited marking	0.4849	0.0029**	0.4705	0.0047**
unidirectional overtaking-prohibited marking	0.8849	0.0124*	0.8845	0.0453*
divisional facilities	-0.4957	0.0402*	-0.4757	0.0461*
lane changing-prohibited facilities	-0.6727	0.0158*	-0.7785	0.0075**
width of dividers for fast and slow traffic modes	0.1223	0.1610	0.1703	0.0513
number of lanes (unidirectional)	0.3020	0.0000***	0.3428	0.0000***
width of the lane at the accident location i (m)	-0.0545	0.0137*	-0.0700	0.0010***
area of junctions (m^2)	0.0002	0.0000**	0.0002	0.1094
traffic control systems				
signalized facilities (the condition of signalized facilities)	-0.2093	0.0976	-0.2868	0.0179*
signal phrase (sec) (signal phase)	0.1633	0.0378*	0.1641	0.0348*
Alpha	0.4396	0.0000***	0.4729	0.0000***

** Significant at 95% ** Significant at 99% ***Significant at 99.9%*

5.1 Road environmental conditions

The result shows that the occurrence of traffic volume is not sensitive to the possibility of BMV conflicts on bridges. The increasing number of BMV conflicts might result from the increasing traffic volume. However, the results reveal that coefficients associated with daily traffic volume are not significant. These results may suggest that road users usually word? decelerate under higher traffic volume, such as during the peak hour, thus reducing the influence of the traffic volume in CBDs, consistent with previous findings (Wang et al., 2004). The study demonstrates that travelling under higher speed or under shorter sight distance, might not directly cause more BMV accidents. However, these factors may significantly increase the severity of BMV accidents, thus vehicles on bridges located in the CBDs are supposed to lower their speed limit to 50 km/hr, and cyclists are supposed to maintain their safety sight distance of at least longer than 30 meters.

5.2 Traffic engineering facilities

Traffic engineering facilities significantly influence the frequency and severity of BMV accidents. These risks may be caused by the type of lane. In the Taipei Metropolis, the majority of lanes on bridges are related to the heterogeneity of traffic velocities. Due to mixed traffic with heterogeneous vehicular velocities, lanes for mixed transport modes are riskier than those for only low and fast transport modes. However, dedicated lanes exclusively for buses or motorcycles significantly increase the risk of BMV collisions on bridges. This is caused by the trespassing of cyclists. Paths prioritizing motorcyclists are even riskier than the dedicated lanes because of much more potential conflicts between motorized vehicles and cyclists. Protective and divided bicycle facilities may greatly reduce BMV accident risks and also prevent potential BMV collisions enhancing road safety.

The way of paving influences cycling collision rates (coefficient = −0.7736). Firstly, asphalt pavement may lower BMV accident rate. However, maintaining the material quality itself is difficult, due to the fact that it is highly sensitive to weather or external forces, causing different levels of damage, such as deformation and cracks. In contrast, rigid pavement, consisting of binding steel with slabs of Portland concrete, may greatly reduce the BMV collisions. Although it diminishes the riding speed and comfort of cyclists, it relatively improves their riding safeness. Also, a base of rigid pavement covered with cobble stones or bricks as an upper layer may reduce BMV collisions more than with only the base layer. This kind of paving may simultaneously lower not only the driving velocities but also the whole speed gap between cyclists and motorists, thus highly improving the safety of cyclists.

Illegal overtaking raises BMV accident frequencies and severities (coefficient = 0.8849, 0.8845). For instance, blind spots are located where there are uni- or bidirectional overtaking-prohibited paths on bridges. Because of low cycling speed, the rear motorized vehicles easily overtake aggressively, resulting in an increased risk. This study also shows that three out of four conflicts in these locations were improper lateral crashes; the minority were rear and frontal crashes. In contrast, lane changing-prohibited facilities and divisional facilities (i.e. channelizing) decreases the number and severity of bicycle accidents (coefficient = −0.6727, −0.7785 and −0.4957, −0.4757 respectively). This decrease of accidents may be attributable to the reduced BMV conflicts. Appropriate remedial measures to the bridge infrastructure, such as reallocating a cycling path on the pedestrian path, widening of the pedestrian path for cycle use, narrowing the lane of motorized vehicles to avoid illegal overtaking, applying lane changing-prohibited facilities, or a well-thought implementation of separated cycle path, minimize the bicycle accident frequency and injury severity.

The dimension of traffic engineering facilities significantly influences accident risks. These risks may result from the increased size of road junctions. In Taipei, junctions with the increased size usually face the complexity of traffic situations, such as speed differentials between bicycles and motorized vehicles, complex traffic composition, and mass traffic volumes, thus increasing the likelihood of bicycle risks. Additionally, lanes may be related to the complexity of traffic situations, such as a road with more numbers of lanes, which is riskier than a normal road.

However, the increased width of lanes may lower accident risks. The result shows that few blind spots are located at wider lanes. Because of the wider lanes, the visibility is enhanced, resulting in a decreased risk. Moreover, a wider width of the lane decreases potential bicycle conflicts with motorized vehicles. This decrease of conflicts may be attributable to the highly strong impact of raised space on driver reaction times. Appropriate remedial measures to the bridge infrastructure, such as widening of the lanes and reducing the number of the lanes may provide more reaction time for the road users, thus minimizing the bicycle accident risk. However, in some cases, the widening of the lanes cannot be done practically????. Designing ancillary bicycle paths combined with pedestrian paths may also reduce bicycle collisions during the mixed traffic situation.

The increased width of dividers for fast and slow traffic modes only leads to higher crash severity (coefficient = 0.1703). In Taipei, most physical dividers are usually made of hard materials. Soft materials may be covered on them as mitigation design for cyclists.

5.3 Traffic control systems

Finally, crashes that involve cyclists may be associated with traffic control facilities. The presence of signalized facilities, which lowers vehicular speeds, decreases the severity of bicycle conflicts. It is also recommended that particular traffic signals for cyclists, such as cyclist or

pedestrian signals, are provided to avoid potential bicycle-motorized vehicle conflicts, thus enhancing road safety.
The longer phase of signalized facilities (i.e. >120 sec per cycle phase of red/amber/green lights for both motorized cycling phase together), may also induce a high accident risk. In Taiwan, long phases mainly occur during off-peak hours. Aggressive driving behaviour, such as accelerating travelling speeds, randomly changing lanes and violating road markings, may easily happen. It is therefore important to properly shorten signalized phases (control travelling speeds) to prevent aggressive driving behaviour, thus reducing bicycle accidents.

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