Article

Influences of Urban Bikeway Design and Land Use on Bike Collision Severity: Evidence from Pohang in South Korea

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Abstract: Since the COVID-19 pandemic significantly impacted mobility patterns, bicycle use and bikeway infrastructure have been spotlighted worldwide. Even before the pandemic, the Korean government expanded bike networks by enacting a national policy. However, issues with bikeway quality have grown significantly due to the excessive installation of bike infrastructure without due consideration given to land use and road conditions. This study aims to investigate bike collision severity based on various kinds of bikeways and land use data from Pohang city, which has a remarkably expanded bikeway network. Bike collision data were analyzed using binary logistic regression. The results indicate that collision severity is associated with the ineffective separation of bikeways, walkway design and pavement materials on side paths, uncleared bike lanes, and land use of planned parks and open spaces. Policymakers can consider these factors to enhance the safety of bikeway networks. These findings highlight the need for bikeway policy improvements for well-designed and managed paved bikeways, particularly on the side paths and in park areas, which ensure pedestrian and cyclist safety.

Keywords: bikeway; collision severity; logistic regression; Pohang

1. Introduction

Since the recent outbreak of COVID-19, serious concerns regarding public transportation have emerged, such as user density on metros and buses [1]. Recently, bicycle use has been underscored as the healthiest and most sustainable mode of transportation [2,3]. Bicycles have been receiving attention in sociocultural and environmental realms because they support pollution abatement, energy conservation, traffic control, and healthy lifestyles [4–8]. Thus, there is high demand for bicycle lane expansion worldwide and many cities plan to increase their construction: 50 km in Paris, France [9], 100 km in Liverpool, England [10], 40 km in Brussels, Belgium [11], 76 km in Bogota, Colombia, 21 km in Barcelona, Spain, 35 km in Milan, Italy, and 100 km in New York City, USA [12,13]. Seoul, the capital of South Korea, also announced a plan to expand its bikeway network by 390 km [13].

The 2009 public policy initiative of low-carbon green development encouraged bike use in South Korea, and subsequently the Master Plan of National Bicycle Policy (2010) and the Basic Plan of National Bikeways (2010) have been implemented. Most cities in South Korea have competitively expanded bikeway networks on urban and regional scales. Owing to the government's efforts, nationwide bikeways more than doubled from 11,387 km in 2009 to 23,849 km in 2019. However, many cities have only concentrated on the quantitative expansion of the length of the bikeway network [14]. There was no consideration of existing roads, sidewalk conditions, and land use along anticipated bikeway installations. To construct more bike lanes, a part of or the entire sidewalk was converted to bike lanes with different pavement materials; thus, both pedestrians and

cyclists were exposed to the danger of collisions and safety issues [15]. However, reports of collision have significantly increased in unorganized bikeways, which are forcefully installed on narrow roads and in residential and commercial areas. Other types of bikeways are not well-integrated with existing transportation systems, posing a serious safety threat to cyclists. The number of bike collisions was 7940 in 2005 and has steadily increased every year. The number of collisions increased to 17,366 cases in 2015 and approximately 13,157 collision cases were reported in 2019 (Figure 1).
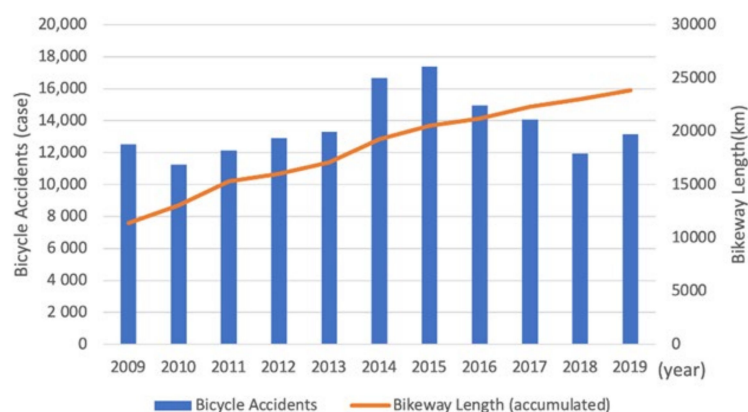

Figure 1. Increasing bike collisions and new bikeway installation (Source: Ministry of the Interior and Safety and Road Traffic Authority, 2020).

Moreover, despite the remarkable expansion of bikeways, the modal share rate of bicycles in South Korea is only 1.6%, below that of the Netherlands (27%), which is a cycling country [16,17]. This result unequivocally shows that the expansion of bikeways is not sufficient to encourage bicycle use. The safety of the bikeway environment can encourage bicycle use as a primary means of commute or for recreational purposes [18]. Thus, it is time to establish delicate strategies for the qualitative improvement of bikeways to ensure cyclists' safety and ultimately facilitate bicycle use. Consequently, the main objective of this study is to investigate the relationships between bikeway design factors and collision severity for cyclists through binary logistic regression analysis, and to suggest tactful bikeway planning for cyclists' safety and the qualitative improvement of bikeways. Particularly, this study deals with land use as one of the significant independent factors of the binary logistic regression analysis to understand the comprehensive urban context in which bikeways have been constructed.

The originality of this study lies in spotlighting the design factors of bikeways that can improve the bikeway environment. Given that existing literature has mostly focused on cyclists' demographical characteristics, cyclists' behaviors, and road infrastructures, bikeway designs have not been sufficiently examined. Thus, this study can contribute to significant design guidelines for more comprehensive bikeway planning and design.

2. Literature Review

Several studies on bike collisions have been conducted around road intersections [19–26] as they are a common site for bike collisions. However, there is a difference between bike collisions at intersections and in single-road environments. While bike collisions on a single road usually depend on the bike infrastructure [27–29], collisions at intersections are significantly influenced by biker behaviors. Thus, the collision severity is less determined by bike infrastructure compared to external factors in the case of cars, such as the amount of traffic, speed, rotation type, and legal violations. This imposes a serious limitation on explaining single-road bike collisions. Thus, studies on such collisions could help expand existing literature.

Various environmental factor studies have been conducted in relation to bike collisions. Reportedly, bikers' blood alcohol levels can affect the severity of biker injury during a collision [29]. Many collisions in Toronto and Vancouver occurred while opening the doors of cars parked along the street [30]. In a factor analysis of collision severity for 4961 cyclists in England, the main contributing factors were revealed as gender, age, weekly cycling distance, cycling experience, stopping behavior at red lights, and the frequency of using minor roads compared to major ones [31]. Poliziani et al. [32] classified cyclists in Bologna, Italy based on three characteristics: risky and hasty (RHC), inexperienced and inefficient (IIC), and sly and informed (SIC), and proved the relations between the three typologies of cyclists' characteristics and route choices. Furthermore, Walker et al. [33] demonstrated the relations between the average waiting time of cyclists and the three behavioral typologies mentioned above. These results may imply that depending on cyclists' characteristics, their travel route choice can be diffused, which is related to bike traffic and even collisions. Meanwhile, road infrastructure environments, such as road obstacles and pavement conditions were the main causes of biker collisions in Switzerland [34]. In the context of South Korea, weather; time; age; gender; collision types; land use; speed limit; riverside areas; separated bikeways; and road environments such as crosswalks, streetlights, and speed bump installations were influential factors for bike collision severity [35,36].

The contribution of this study is to especially focus on the design factors of bikeways to explain bicycle collision severity and suggest tactful bikeway planning strategies with design perspectives toward qualitative improvements and enhanced cyclist safety. While existing literature has extensively investigated the environmental determinants of the severity of bicycle collisions, few studies have examined the association between characteristics of bikeway designs and cyclist collisions. Since the necessity of separate bike lanes in most cities is debated [37], some scholars have also highlighted that bikeway planning should be critically integrated within the framework of urban traffic planning and management [38,39]. Moreover, Beyeon, Im, and Yun highlighted the necessity of land use patterns with different bikeway designs and typologies, because the bikeway environment is intermingled with road width, pedestrian density, the intensity of vehicle traffic, and the street environment, all of which are closely associated with land use patterns [40]. Therefore, this study also considers land use patterns as a significant factor to comprehensively discuss the relationships between bicycle collision severity and bikeway designs. Consequently, this study involves a binary logistic regression analysis to explore the correlation between bicycle collision severity and diverse independent variables including bikeway types and land use patterns.

3. Materials and Methods

3.1. Site Selection and Data Collection

The spatial scope of this research is Pohang city in South Korea, which has remarkably extended its bikeway network over the last decade. Since the Action Plan for Cycling Promotion per the national policy was enacted, the city has installed considerable bikeway infrastructure on existing roads and streets. As a result, the total bikeway length in the city increased 12 times from 2011 (34 km) to 2018 (413.45 km) (Figure 2). Although the bikeway infrastructure has considerably increased, the number of bicycle users has not significantly risen; yet, many bike collisions have been continuously reported, including 170 cases in 2011, 217 in 2013, 255 in 2015, 212 in 2017, and 201 in 2019 [41]. Therefore, Pohang is a suitable city for investigating this research question.

Data on bike collisions were collected from the Traffic Accident Analysis System (TAAS), which is a national database of injury records, by sending a formal request for data collection. The data are accumulated from the police and insurance companies in the system and they include only collisions of human-powered bicycles. We collected the TAAS data of 1904 bike collision cases in Pohang from 2011 to 2019, but 185 cases were removed due to unidentified information. Further, 854 road intersection cases were excluded. Finally, we found that 865 collision cases occurred in bikeway areas which were then used for our

investigation. To examine bikeway design types and conditions, bikeway site visits and observations were conducted in Pohang from March to August in 2020. Land use and other data on bikeways were provided by Pohang city and derived from the 2018 Master Plan of Bikeway City Pohang.
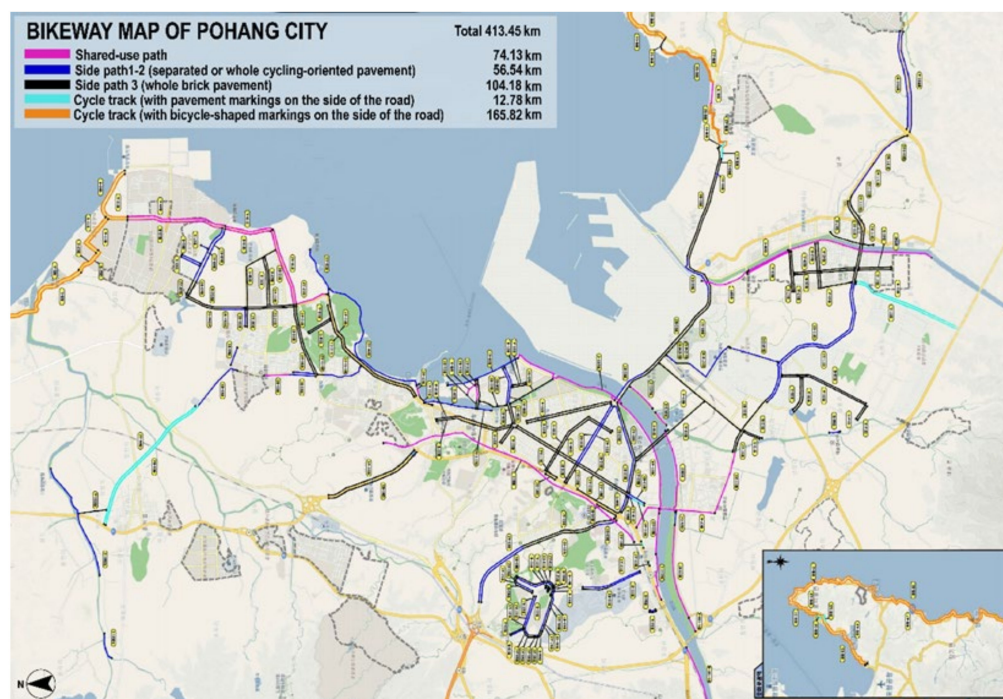

Figure 2. 2018 Pohang city bikeways map (most recent) (Source: [41]).

3.2. Analytical Modelling

Using a binary logistic regression model, this study aimed to explore the independent variables of bikeway types and land use. The binary logistic regression model is useful when the dependent variable is categorical and takes only two values, 0 or 1. Given that cyclists' collision severity can be separated to minor (0) and major (1) as a dependent variable, using the binary logistic regression model is appropriate in this analysis. The binary logistic regression function can be derived by logit transformation, which is a functional conversion taking a natural logarithm to odds ratio.

The transformed odds ratio is equivalent to a linear regression function as follows:

$$log_e\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_M x_{iM} \tag{1}$$

Here, $\frac{P}{1-P}$: Odds Ratio of the Dependent Variable
β: Coefficient of Regression
x_i: Independent Variable

By simplifying Equation (1), the final binary logistic regression function can be derived as follows:

$$P_i(y_i = 1|x_i) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_M x_{iM})}} \tag{2}$$

Here, P_i: Collision Severity of Cyclist (Dependent Variable)
$P_i = 0$: Minor Collision, $P_i = 1$: Major Collision
x_i: Cyclist Collision Severity Impact Variable (Independent Variable)
β: Coefficient of Logistic Regression Mode

3.3. Variable Selection for the Binary Logistic Regression

This study aims to evaluate the correlation between the severity of collisions of cyclists and bike lane classification, and the influencing factors, including land use. The severity of bike collisions is defined as "the victim suffering minor, major, or fatal injury" [20]. The National Police Agency of Korea officially defines minor and major injury as requiring less than and over three weeks of medical treatment, respectively. The cases of fatal injury in this study did not exceed 1%, and thus, the severity of collisions was classified as minor and major severity (major and fatal). Thus, the dependent variables were set up as minor injury (0) and major injury (1). Considering the literature review, TAAS dataset, and our research purpose, the six independent categorical variables selected were gender, age, time, road surface condition, land use, and bikeway type (see Table 1).

Table 1. Independent variables and descriptions.

Variables		Description
Gender		Gender of cyclists (Female: 0, Male: 1)
Age	Under 30	Reference variable
	30–49	Age of cyclists (<30: 0, 30–49: 1)
	50–69	Age of cyclists (<30: 0, 50–69: 1)
	Over 70	Age of cyclists (<30: 0, $\geq$70: 1)
Time		Time of collision cases(Night: 0, Day: 1)
Road surface condition		Road surface condition of collision cases (Others: 0, Dry: 1)
Land use	Residential	Reference variable
	Commercial	Cases of collisions on roads in commercial areas (Residential: 0, Commercial: 1)
	Industrial	Cases of collisions on roads in industrial areas (Residential: 0, Industrial: 1)
	Parks and open spaces	Cases of collisions on roads in parks and open spaces (Residential: 0, Parks and open spaces: 1)
Bikeway type	T0: No lane	Reference variable
	T1: Shared-use path	Bake lane clearly isolated; bike lane in the park (T0: 0, T1: 1)
	T2: Cycle track	Bike lane separated from the road by pavement markings or signages (T0: 0, T2: 1)
	T3: Side path 1	Bike lane with whole cycling pavement on the sidewalk (T0: 0, T3: 1)
	T4: Side path 2	Bike lane with separated cycling-oriented pavement on the sidewalk (T0: 0, T4: 1)
	T5: Side path 3	Bike lane with whole brick pavement on the sidewalk (T0: 0, T5: 1)

Note: Nighttime designated as 06:00–17:59 and daytime designated as 18:00–05:59.

The novelty of this study lies in analyzing correlations of bicycle collision severity especially with bikeway types, which has not been considered in previous studies. However, the four official bikeway types defined by the Korean government have not reflected the real urban context, although there has been a notable increase in the country's bikeway length. Hence, the four official bikeway types were further divided into six types based on site visits and field observations of the detailed design of side paths. Although there are various pavement sizes and compositions in the existing sidewalk, this bikeway type is most commonly installed. During the last nine years in Pohang, most collisions have occurred with this bikeway type. Thus, this design needs to be understood in greater detail. Table 2 shows detailed descriptions of the independent variables of the six bikeway types. This study also seeks to understand the influence of land use on bikeway designs and bicycle collision severity. As the TAAS data provide coordinates of all bicycle collisions

during the period, land use information regarding specific sites of bicycle collisions could be utilized for analysis.

Table 2. Detailed descriptions of the six types of bikeways.

	Type	Description	Example
T0	No lane	No distinction between car traffic, walkway, and bikeway/Usually paved with asphalt	
T1	Shared-use path	Mostly constructed near parks and rivers Clearly isolated road and sidewalks by vertical and horizontal way/Usually paved with asphalt, concrete, or unsealed surface with granular materials	
T2	Cycle track	Separated horizontally from the traffic lane by tubular marker, pavement marking, signage, vertically from sidewalk by raised curb/Sometimes sidewalk is not constructed/Usually paved with asphalt	
T3	Side path 1 (whole cycling pavement)	Dual lane horizontally separated from the road for bicycles and pedestrians with a bike-only pavement/Usually paved with colored asphalt, bituminous slurry, concrete, or unsealed surface with granular materials	
T4	Side path 2 (separated cycling pavement)	Dual lane vertically separated from the road for bicycles and pedestrians with a separation of cycling-oriented pavements and sidewalk blocks/Usually paved with asphalt, concrete, and bituminous slurry	
T5	Side path 3 (whole brick pavement)	Dual lane vertically separated from the road for bicycles and pedestrians with sidewalk blocks/Usually paved with sidewalk blocks	

Source: Authors.

In the binary logistic regression, each categorical independent variable should be divided into all its values called dummy variables, and one value is extracted as a reference variable to contrast with the remaining dummy variables with respect to the dependent variable. Hence, "female" in gender, "under 30" in age, "night" in time, "others" in road surface condition, "residential" in land use, and "no lane" in bikeway type were designated as the respective reference variables.

4. Results

4.1. Descriptive Statistics

Table 3 shows the descriptive statistics for the collision severity of 865 cyclists who experienced bicycle collisions between 2011 and 2019 in Pohang city. The collision frequency

of males was almost three times higher than that of females. The cyclists from the older age group (50 s and 60 s) experienced the largest number of collisions. More collisions occurred during the daytime and dry conditions on the bikeway road surface, but collisions that were more serious occurred on wet bikeway surfaces. Most of the collisions occurred in residential and commercial areas, and minor collisions were more frequent than major collisions. However, the land use of parks and open spaces showed more cases in the major severity group. Major collisions were more frequent than minor collisions in types 2, 3, and 4.

Table 3. Descriptive statistics of the 865 victims who experienced bike collisions.

		Collision Severity (Case)		
		Minor	**Major**	**Total**
Total		495	370	865
Gender	Female	127	98	225
	Male	368	272	640
Age	Under 30	129	65	194
	30–49	80	55	135
	50–69	195	159	354
	Over 70	91	91	182
Time	Day	375	283	658
	Night	120	87	207
Road surface condition	Dry	478	348	826
	The others	17	22	39
Land use	Residential	268	156	424
	Commercial	168	151	319
	Industrial	16	12	28
	Parks and open spaces	43	51	94
Bikeway type	T0	126	66	192
	T1	2	2	4
	T2	19	20	39
	T3	12	13	25
	T4	86	90	176
	T5	250	179	429

4.2. Binary Logistic Regression

Table 4 shows the results of the binary logistic regression analysis. The variables with a significance level of less than 5% indicate positive (+) values in the odds ratio (OR) of this analysis and are expressed as follows: 50–69 years of age (OR: 1.512), over 70 years of age (OR: 2.008), parks and open spaces (OR: 2.283), T2 (OR: 2.601), T4 (OR: 2.161), and T5 (OR: 1.556). This means that cyclists of the age group 50 to 69 years have 1.512 times the possibility of major collision severity compared to the group under 30 years (reference variable). The group over 70 years is 2.008 times more likely to experience a major collision than the group under 30. For land use, the possibility of major collision severity in parks and open spaces is 2.283 times higher than that in residential areas (reference variable). For bikeway types, T2 (cycle track) had a 2.601 times higher rate of major collisions than T0 (no lane, reference variable), and T4 (side path 2 with separated cycling pavement) had a 2.161 times higher rate of major collisions than T0. In the case of T5 (side path 3: whole brick pavement), a 1.556 times greater risk of major collision severity compared to T0 was noted.

Table 4. Results of the binary logistic regression.

Variable	OR	95% CI	*p*-Value
		Gender	
Female	1.000	ref.	-
Male	0.945	(0.678–1.317)	0.737
		Age	
Less than 30	1.000	ref.	-
30–49	1.320	(0.816–2.137)	0.258
50–69	1.512	(1.028–2.225)	0.036*
Over 70	2.008	(1.308–3.084)	0.001**
		Time	
Night	1.000	ref.	-
Day	1.090	(0.780–1.524)	0.613
		Road surface condition	
Others	1.000	ref.	-
Dry	0.578	(0.295–1.132)	0.110
		Land use	
Residential	1.000	ref.	-
Commercial	1.216	(0.863–1.712)	0.264
Industrial	0.990	(0.436–2.248)	0.982
Parks and open spaces	2.283	(1.403–3.715)	0.001 **
		Bikeway type	
T0: No lane	1.000	ref.	-
T1: Shared-use path	1.619	(0.204–12.880)	0.649
T2: Cycle track	2.601	(1.003–4.234)	0.049 *
T3: Side path 1	2.103	(0.883–5.009)	0.093
T4: Side path 2	2.161	(1.324–3.527)	0.002 **
T5: Side path 3	1.556	(1.065–2.275)	0.022 *

Note: "OR" represents the odds ratio. "CI" stands for confidence interval. "ref" means reference variable. ** denotes 1% significance level; * denotes 5% significance level. The Hosmer–Lemshow test was conducted to assess how well the model fits the data by comparing the observed and expected frequencies of events and non-events. The test's *p*-value is 0.973, which is larger than the 5% significance level. Additionally, the model's classification accuracy was 61.0%. Therefore, there was no error in the model structure.

5. Discussion

The research results indicate the importance of bikeway design and location, which influence bike collision severity; thus, they have critical implications for safe bikeway environment planning. Transportation policymakers need to devise more detailed design guidelines and regulations on safety and public health to encourage bicycle use.

5.1. Need for Clear and Solid Separation between Bikeways and Roadways in Parks and Open Spaces

Many cyclists in South Korea often ride bicycles in parks and open spaces for leisure. There were 43 minor collisions (45.7%) and 51 major collisions (54.3%) in these areas, resulting in 94 cases. Although these are fewer in number compared to the collisions in residential and commercial areas, major injuries occur more frequently than minor injuries. Moreover, the possibility of having major collisions is 2.283 times greater than in residential areas. Therefore, it is necessary to manage bikeways in parks and open spaces to ensure the safety of cyclists.

T2 (cycle track), which is designated based on motorized traffic by stripping, signage, and pavement markings, is the most frequent type constructed in parks and open spaces

(Figure 3). Pavement marking, particularly, has been used to construct this type of track. In this case, however, if a car is parked on the cycle track, cyclists need to maneuver onto the driving lane to avoid it. Moreover, this type of bikeway is usually constructed on the outskirts of a city with high-speed cars and heavy transit of large cargo trucks [42]. Sometimes cycle tracks have physical barriers such as tubular markers, bollards, and raised curbs. Unfortunately, many cars park in the lanes breaking the physical barrier (Figure 3). For these reasons, cyclists have not enjoyed the preferential or exclusive use of these bikeways.

Figure 3. T2-cycle track: with a signage on the side of the road (**left**), T2- cycle track: tubular markers broken by parked cars (**right**) (Source: authors).

Additionally, some cycle tracks let cyclists share the road with motor vehicles using bicycle-shaped pavement marking on the side of the road (Figure 4). Although this kind of design has been observed in areas with low car traffic, motorists travel at high speeds due to the low traffic. Furthermore, because of the winding roads, it is difficult for motorists travelling at high speeds to notice cyclists; therefore, there is a high risk of cars crashing into the rear of bicycles. For instance, 19 minor collisions (48.7%) and 20 major collisions (51.3%) occurred in T2, resulting in 39 cases, and there is a 2.601 times greater possibility of major collision severity than T0. On the contrary, T1 (shared-use path), which is also constructed mostly in parks and open spaces, shows only a total of four collisions with two major cases over the same period (Figure 4). T1 has been constructed mostly in parks and riversides, showing a clear delineation from traffic lanes and even the walkway. Therefore, policymakers should consider expanding the T1 concept that divides the bikeways from the other pathways. If the road can no longer be widened, such work must be carried out even if it shrinks the traffic lanes.

Figure 4. T2-cycle track: Bicycle-shaped marking on the side of the road (**left**), T1-shared-use path, which is the most appropriate bikeway design (**right**) (Source: authors).

5.2. Importance of Pavement Materials in Side Paths

Due to the narrow width of roads in residential and commercial areas, side paths (T3, T4, T5), which are used by both pedestrians and cyclists, are commonly constructed nationwide (Figure 5). However, the quantitative expansion of the length of the bikeway network concentrating excessively on the side paths has further compromised the safety of cyclists. In contrast to the case of T0 without the division between motorists, cyclists, and pedestrians, only cyclists and pedestrians use the side path, which entails high speeding by cyclists. In the T5 (side path 3 with whole brick pavement), which is the most prevalent bikeway type in South Korea, cyclists who are no longer obstructed by motor vehicles can speed freely, which can lead to more severe collisions for cyclists than T0. The research results show that in the case of T5, there is a 1.556 times greater possibility of major collision severity than T0.

Figure 5. T3-side path 1 (**left**), T4-side path 2 (**middle**), T5-side path 3 (**right**) (Source: authors).

T4 (side path 2: separated cycling pavement), in which the bikeway is differentiated from the walkway by its pavement, is a more developed type than T5. However, cycling-oriented pavements, such as permeable cement concrete for separation, incite more high-speed cyclists. Above all, such separation has not been effective; pedestrians have often been seen to ignore the separation and freely wander in both bikeways and walkways. According to the research results, in the case of T4, there is a 2.161 times greater possibility of major collision severity than T0. Therefore, the government should refrain from constructing the side paths without consideration of its qualitative improvement; the side paths should ensure a conspicuous separation between walking and cycling through durable physical barriers.

However, in many districts, it is impossible to separate them due to narrow sidewalks. In this case, an entirely cycling-oriented pavement was recommended. In the last nine years, the number of collisions in T3 (side path 1: whole cycling pavement) was 7.04 and 17.16 times less than T4 and T5, respectively. The number of major collisions in T3 was 6.92 and 13.76 times less than T4 and T5, respectively. These results are related to the shared space density and diversity of movement directions. which Alsaleh et al. [43] have emphasized in the study of behavioral analysis of cyclist and pedestrian interactions; pedestrian-oriented pavements, such as brick pavements (T5), make pedestrians freely move in more unexpected directions than T3. Thus, cyclists travelling at high speeds can hit pedestrians who may not see them approaching fast enough.

5.3. Importance of Non-Motorist-Centric Design in Low-Volume Streets without Sidewalks

Numerous low-volume residential and commercial streets in Korea were designed without sidewalks. T0 (no lane) is representative of these streets (Figure 6). According to Korean law, under the Promotion of the Use of Bicycles Act, T0 is not classified as a bike lane. However, it is prudent to consider it as a type of bikeway and redesign it to de-emphasize motor vehicle transportation on the streets.

In low-volume streets such as T0, pedestrians, cars, and bicycles were found to be mixed haphazardly. Although most T0s are in residential and commercial areas where pedestrians and cyclists have considerable movement, they have a traditional auto-centric paradigm; all the road designs are focused on car traffic. Thus, cyclists are forced to slow

down with caution. For this reason, 65.6% of the collisions at T0 showed minor severity. However, considering 192 bike collisions at T0, which is the second largest number of cases of the six types, it is necessary to redesign these narrow, auto-centric, and pedestrian heavy streets to ensure the public safety of cyclists and pedestrians.

Figure 6. T0-no lane (**left**); serpentine and pedestrian-oriented Woonerf Street (**right**) (Source: Copyright from methleys.headstogether.org/. The photo on the left is taken by the authors).

In the late 1960s, "Woonerf," the first Dutch street to achieve livable conditions and safety, was developed by urban designers, urban planners, and traffic engineers, alongside the participation of residents [44]. They replaced bricks with serpentine lanes and placed street furniture (e.g., trees and benches), which successfully forced motorists to slow down and be careful, without a conspicuous separation between motorists and non-motorists [45]. Furthermore, an increase was observed in the social interaction and satisfaction level of the residents in Woonerf, as well as a decline in collision cases [46]. This concept of shared streets has been widespread in many countries and adopted globally [47,48]. This design concept of enhanced health and safety in neighborhoods should also be applied to T0 streets in South Korea. For the concept to be well-implemented in T0, policymakers must consider initial physical changes, such as street furniture or a winding street design that strengthens the non-motorist-priority environment of the street.

6. Conclusions

Despite the government's efforts over the past decade to extend the length of bikeways, the ill-considered extension did not include the safety factor with respect to pedestrians and cyclists. This has resulted in the construction of low-quality bikeways across the country. With the increasing proliferation of interest in bicycle use during the pandemic, this problem will become even more prominent. Thus, an analysis of the problems of bikeways must be conducted to plan for safer bikeway construction. To analyze this issue, Pohang city, one of the world's most active cities for bicycle usage, was investigated. Binary logistic regression was used to identify factors affecting the severity of bike collisions. The key factor is the bikeway type, which is reclassified into six types based on lane design, pavement materials, and land use types at the collision location. The study results indicate that the land use of parks and open spaces and bikeway types of T2 (cycle track), T4 (side path 2: separated cycling pavement), and T5 (side path 3: whole brick pavement) are correlated with bike collision severity. Therefore, T2 in parks and open spaces is needed to install clear and solid physical division, which can conspicuously designate bikeways by reducing the width or the number of lanes. Additionally, the government should refrain from constructing side paths, without serious consideration of road conditions, for the sake of quantitative expansion of bikeways. While constructing a side path, it is necessary to install physical barriers on the separated lanes to separate the bikeway from the walkway. If the narrow roads present an unavoidable limitation for separation, cycling-oriented pavement is recommended. It is also necessary to deal with T0 (no lane) as a bikeway. It

should be redesigned to mitigate the dominance of motor vehicles on the streets. This study is significant in that it analyzed each reclassified bikeway and proposed design solutions for optimal safety. Based on this study, policymakers could consider clear separation from motorways and safe road designs that factor in cycling-oriented pavements, ensuring pedestrian and cyclist safety compared to low-volume streets without sidewalks.

This study has certain limitations. The TAAS data used in this study are created based on data received by the police and insurance companies; thus, if the severity of the injury is low or if it is a single collision, it may not have been reported. Therefore, there is a possibility of missing data. Further, the data included only human-powered bicycle collisions. Given that there has been an increase of users of electric bikes (E-bikes) and kickboards (E-kickboards) in South Korea, further investigation of E-bike and E-kickboard collision severity with bikeway design can be conducted. Additionally, if more comprehensive factors that can influence collision severity and bikeway design (such as bike traffic and characteristics of cyclists) are utilized for future studies, more delicate strategies may emerge to improve bikeway designs and enhance cyclist safety. Lastly, this study depends on collision datasets reported by the agencies; more in-depth interviews with injured bikers can contribute to better accuracy of the study findings. Future studies could focus more on qualitative analysis with in-depth surveys to better assess collision circumstances and conditions.

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