RISK FACTOR ANALYSIS OF BICYCLE ACCIDENTS AT INTERSECTIONS

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This study analyzed the risk factors for bicycle accidents in the central business district of Nagoya City, Japan, based on traffic accident data from 2016 to 2020, traffic volume data from 2019 to 2020, and geometric intersection feature data from 2022. The univariate negative binomial model was used to estimate the risk factors. Overall, bicycle-related accidents occurred more frequently when the car traffic volume was large. The result shows that the intersection having a cross shape, the existence of right- or left-turn exclusive lanes at intersections, and the existence of guardrails or curbstones on the sidewalks around the intersections increased the occurrence of bicycle-related accidents. In addition, all intersection arms with traffic signals contributed to reducing the occurrence of bicycle-related accidents.

Key Words : *Traffic safety, bicycle accident, intersection geometry, traffic volume, negative binomial model*

1. INTRODUCTION

(1) Background

Cycling has become an increasingly popular transport mode worldwide, with advantages such as lower cost, health, environmental friendliness, and high efficiency for short-distance travel. Governments and organizations have promoted cycling as a sustainable transport method to reduce traffic pollution and congestion. For example, Toronto's Cycling Network Plan, which began in 2016, aims to expand the current network of cycling routes and renew existing networks with cycling infrastructure, such as bicycle lanes and bicycle parking, to increase convenience and safety[3)].

There was a significant increase in bicycle sales in 2020 due to Covid-19[1)]; the use of bicycles as a fundamental mode of transit increased, not only for social distancing but also for physical activity during the pandemic. There is also a new trend in e-bikes. With the increasing number of bicycles, safety is a concern.

Japan has a high modal share of bicycles (16%), ranking third in the world in 2015, after Denmark and the Netherlands[7)]. Cyclists accounted for 17% of all road fatalities in 2020 [8)]. Although the total number of bicycle-related accident fatalities has decreased over the past 30 years, the road fatality percentage for cyclists has increased.

Nagoya City, the fourth largest city in Japan with a population of 2.3 million in 2015, has a high traffic volume[9)]. There are many private passenger car users, and the largest automotive industry clusters in Japan are also in Aichi Prefecture. Nagoya City's proportion of automobile use is higher than that of the Tokyo Metropolitan Area and Osaka City, leading to several issues such as environmental pollution and road safety problems[2)].

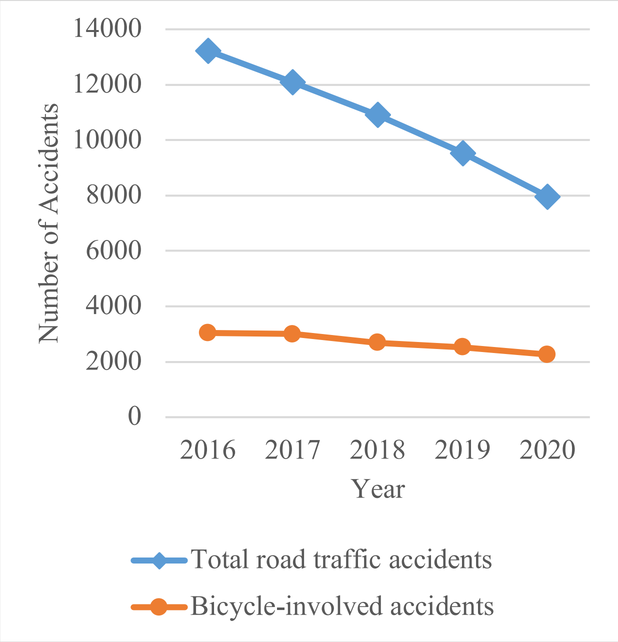

Fig. 1 Road injury accidents and bicycle-involved injury accidents in Nagoya City from 2016 to 2020

As shown in Figure 1 based on road injury accident data in the Aichi Prefecture from 2015 to 2020, the total number of traffic accidents decreased significantly. Although the number of bicycle accidents has decreased in recent years, the percentage of bicycle accidents over total accidents has increased since 2016.

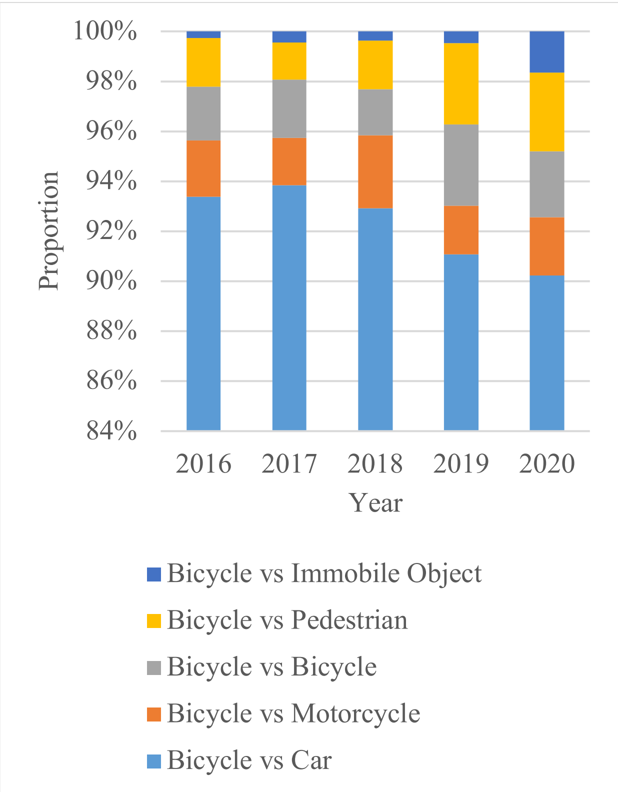

Fig.2 Bicycle-related accidents by accidents type

As shown in Figure 2 which sort the accident data by the bicycle accident types involving car, motorcycle, bicycle, pedestrian, and immobile object, it is obvious that most are bicycle versus cars. Therefore, the car traffic volume can be a key factor in the bicycle accident risks.

(2) Research Objective

Based on data from 2006 to 2015, Nagoya City had a high number of traffic accidents in Japan, and approximately 80% of bike accidents occurred at intersections. This study aims to find solutions to reduce bicycle accidents in Nagoya City by analyzing risk factors using accident data from 2016 to 2020 and recent annual car traffic volumes at intersections in the central business district (CBD). The broader aim is to achieve a safer and more sustainable transportation environment and contribute to transportation safety solutions with the increasing global bicycle usage.

(3) Literature Review

With the growing safety concerns on road transportation, there are many previous studies on risk factors of accidents. For bicycle-related accidents, these studies can be generally divided into two levels – the macroscopic level and the microscopic level. The macro-analysis focuses on the zone level[6] while the micro-analysis focuses on specific intersections[11]. The Poisson model and the negative binomial model are two generally used models for crash data analysis. The negative binomial model is feasible for identifying the influence of traffic volume and geometrical factors on the frequency of accidents at intersections[10].

"Comparative analysis on bicycle accident risk factors among age groups at zone level" uses a multivariate Poisson gamma count model, it has found that elderly bicycle accidents occur more frequently on longer bicycle roads[6]. "Injured cyclists with focus on single-bicycle crashes and differences in injury severity in Sweden" using the binary logistic regression model figures out that elders and men have higher severe injury occurrence rates at intersections[5]. "Effects of road network characteristics on bicycle safety: a multivariate Poisson-lognormal model" finds that land use, public transportation stations and road density affect the occurrence of bicycle-involved accidents[4].

The previous study "Risk factor analysis of bicycle accidents considering geometric features and bicycle road at intersections" of the Nagoya City CBD area used a Negative binomial model to analyze traffic accident data from 2006 to 2015 and intersections geometric features from 2020. It figures out that there is a high risk of bicycle accidents occurring at wider intersections, intersections with stop signs on all arms, and intersections with pedestrian signals on some arms[11]. Research in more recent years is needed due to the updating of bike infrastructures and policies. This study uses updated traffic accident data from 2016 to 2020, and intersection geometric features in 2022. Moreover, a new data resource – traffic volume data from 2019 to 2020 is also included as a factor.

2. DATA DESCRIPTION

(1) Study Area

Figure 3 shows the distribution of the total accidents in Nagoya from 2016 to 2020 by the one-kilometre mesh. The CBD area was chosen as the study area because it had a higher traffic accident density. The target CBD area is around two-kilometre squares located in the central area of Nagoya city, which is defined as the region formed by Suginomachi Road in the north, Akamon Road in the south, Hanazono Road in the west, and Buhei Road in the east. There are 173 objective intersections with both the traffic volume data and accident data in the study area.

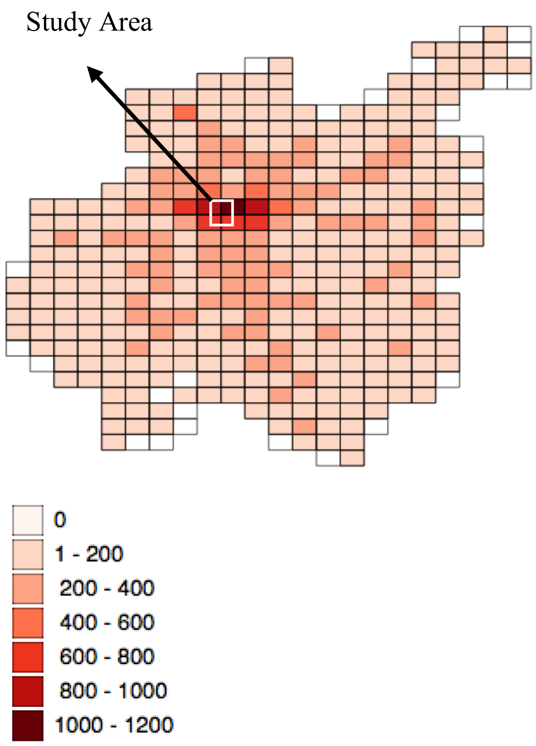

Fig.3 Distribution of total accidents from 2016 to 2020

As shown in Figure 4, bicycle-related accidents happened more centrally in the CBD area compared with the distribution of total accidents in Figure 3. Therefore, Nagoya City CBD area is a suitable choice for the study of bicycle-involved accidents.

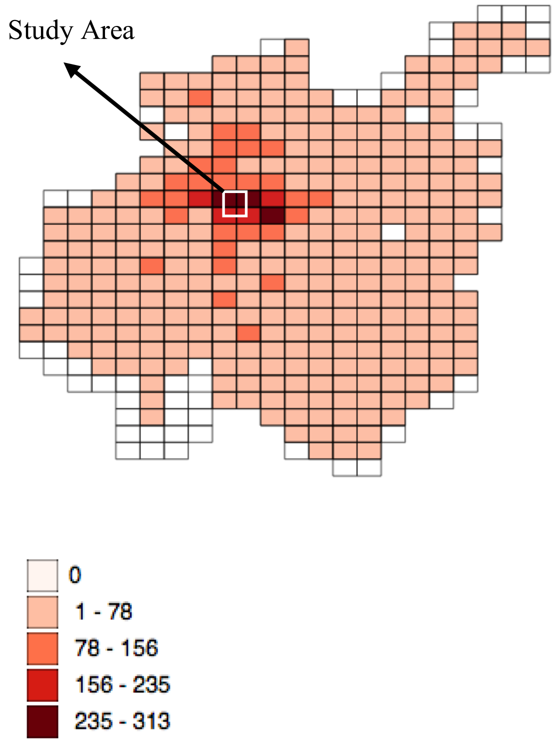

Fig.4 Distribution of bicycle-related accidents from 2016 to 2020

(2) Data Source

Three main data sources are used in this research:

(a) Raw traffic accident data from 2016 to 2020 in Aichi Prefecture provided by the Aichi Prefecture Police Office. The recorded data includes information on the accident type, level of injury, weather, location, age groups, etc.

(b) Intersection geometric features are collected by using Google Earth and Google Street View. The data include the intersections' physical elements such as intersection shape, median central strip, left/right turn exclusive lane, traffic signal, pedestrian signal, pedestrian crosswalk with bicycle exclusive path, and sidewalks with guardrail or curbstone on the occurrences of bicycle accidents at the intersections.

(c) Hourly traffic volume for cars at intersections from October 2019 to December 2020 from the KDDI Location Analyzer which is a geographic information system with mobile GPS data (KDDI Location Analyzer, 2021). The collection periods are generally the average hourly traffic volume during three months; however, April, May, and June 2020 collected monthly average hourly traffic volume as the traffic volume was not regular due to the pandemic. The collected traffic volume data are the total car traffic volume for each intersection during the whole collection period with characteristics like weekday and weekend, gender, age groups, the purpose for travelling, etc. The annual average traffic volume (AADT) was calculated for each intersection from the collected data.

3. BASIC DATA ANALYSIS

(1) Accidents Data

The raw traffic accident data were sorted out in the study area by latitude and longitude. There are a total of 2185 accidents in the study area from 2016 to 2020. Among them, there was 1615 bicycle-involved accidents. The number of bicycle accidents by year in the study area follows the similar decreasing trend as that of the Nagoya City. However, the percentage of accidents happened in intersections is increasing. As shown in Figure 5, most bicycle-related accidents occurred at intersections.

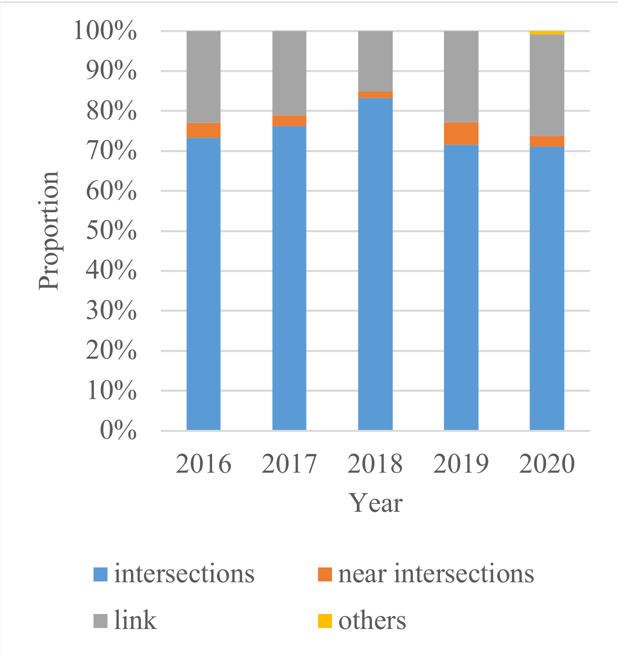

Fig.5 Bicycle-involved accidents road shape (100%)

The study area has 618 bicycle-related accidents happened at intersections in these five years. The number of bicycle-related involved accidents is analyzed according to the type of analyzed into two parts – bicycles as the first party and bicycles as the second party. The party primarily responsible for the crash was labelled as the “first party”, and the party secondarily responsible for the accident was labelled as the “second party”.

As shown in Figure 6, although the number of accidents when bicycles as the first party increased since 2018, it is small and fluctuated in these years. The accidents between bicycles to pedestrians and between bicycles to cars are the main ones.

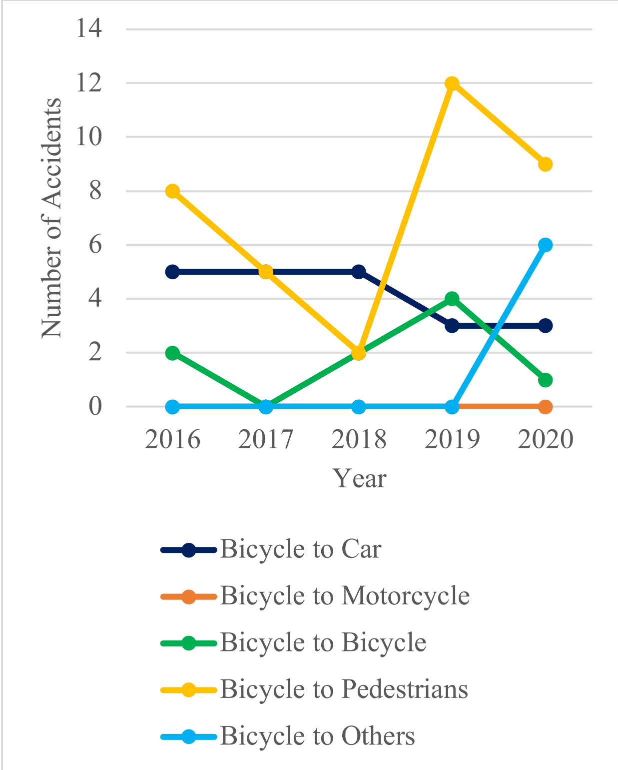

Fig.6 Number of accidents with bicycle as the first party

As shown in Figure 7, the number of accidents when bicycle as the second party is large and it decreases since 2017. Accidents between cars to bicycles are the most dominant accident. It shows that bicycles can be the second party in most cases rather than to be the first party.

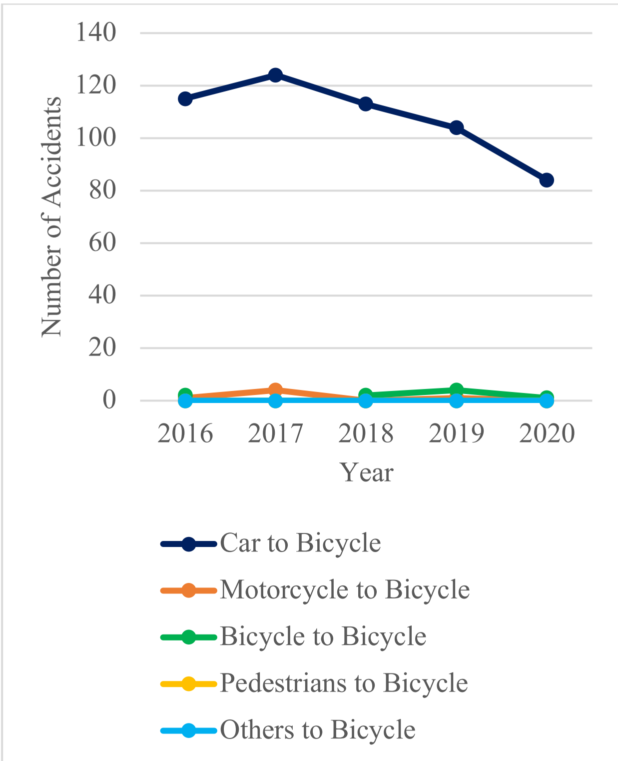

Fig.7 Number of accidents with bicycle as the second party

(2) Traffic Volume Data

After collecting the KDDI traffic volume data, these data are checked and analyzed. The validity of the traffic volume data collected from the KDDI location analyzer has been checked based on traffic census data in 2015. In general, the KDDI data validity in the study area was acceptable with a 77% similarity in total corresponding census samples. Moreover, five intersections are randomly picked up to analyze the car traffic volume changes during the collected period as shown in Figure 8 for weekday 12 hours and Figure 9 for weekend 12 hours.

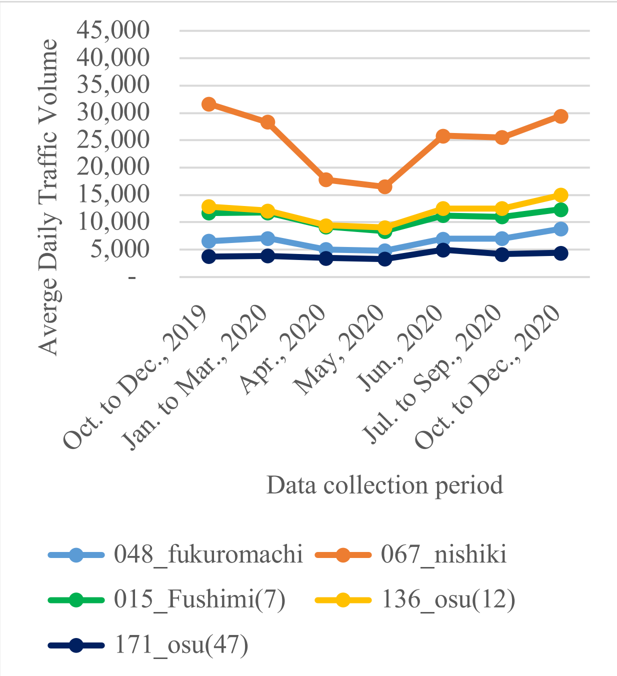

Fig.8 Weekday 12hrs traffic volume at particular intersections

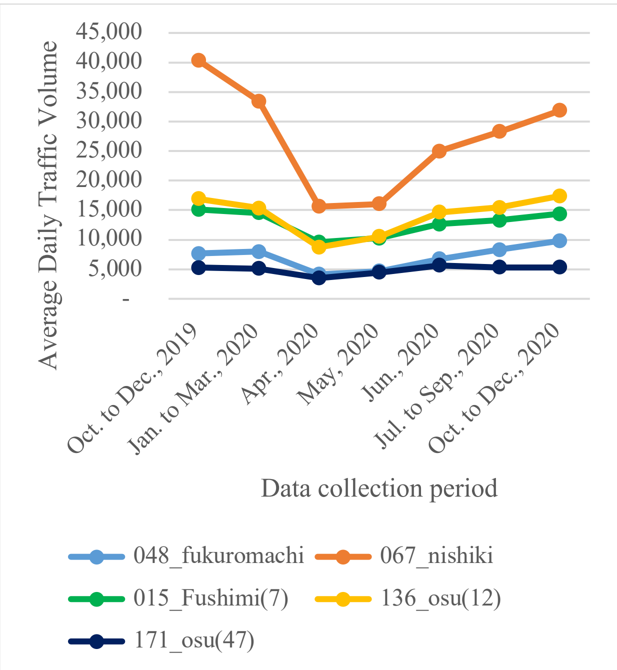

Fig.9 Weekend 12hrs traffic volume at particular intersections

The variation of traffic volume in the five intersections shows a similar trend. The number decreased a lot between January 2020 and May 2020, especially in April, due to the declaration of emergency during COVID-19. The traffic volume increased after May 2020 due to the end of self-restraint. The increasing trend may result in a similar level of traffic volume or even exceeds that before the pandemic.

The decreasing car traffic volume due to the pandemic can influence the number of accidents between bicycles and cars, which is the major accidents type of bicycle-related accidents. To cover data before, during, and after the pandemic, AADT for each intersection is calculated within the period of October 2019 to September 2020. The traffic volume data is matched with the survey data which has intersections geometry conditions by latitude and longitude to prepare the dataset for the following analysis. There are 173 intersections matched as the objects of the study.

In the objective 173 intersections, there are 448 bicycle-related accidents in a total of 1615 accidents at intersections from 2016 to 2020. Among them, 399 accidents are between cars and bicycles. To be more specific, 385 accidents are cars to bicycles, which means in most cases bicycle is the secondary responsible party. As shown in Figure 10, around one-quarter of the intersections have no bicycle-involved accidents, and most intersections have fewer than six accidents.

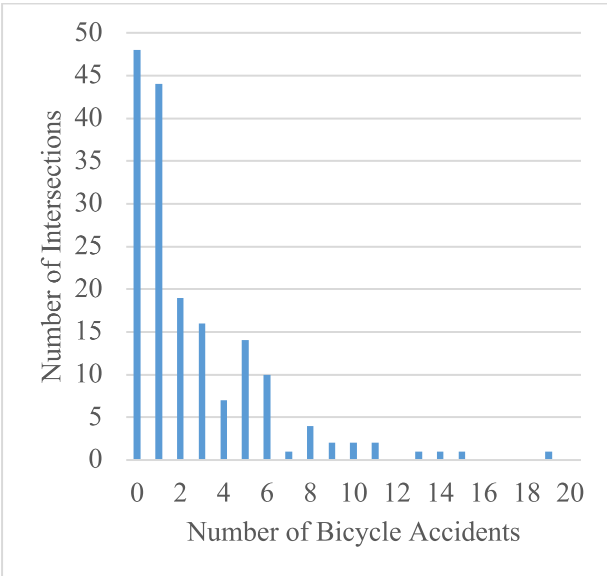

Fig.10 Distribution of bicycle-related accident frequency

4. METHODOLOGY

In the study, the negative binomial model is used to analyze the effect of risk factors of intersections geometry such as Intersection shape, median central strip, left or right turn exclusive lane, traffic signal, pedestrian signal, pedestrian crosswalk with bicycle exclusive path, sidewalks with guardrail or curbstone, bicycle lanes in Fushimi and Sakura street, as well as car traffic volume on the occurrences of bicycle-related accidents at intersections.

The negative binomial model is a widely used count data analyzer that addresses the over-dispersion problem by identifying significant explanatory variables.

$$P(y_i) = \frac{\Gamma(\theta_i + y_i)}{\Gamma(\theta_i) y_i!} \left(\frac{\theta_i}{\theta_i + \lambda_i}\right)^{\theta_i} \left(\frac{\lambda_i}{\theta_i + \lambda_i}\right)^{y_i} \quad (1)$$

where,
P(y_i): probability of intersection i having y_i bicycle accidents; Θ: the over-dispersion parameter; λ_i: the expected number of bicycle accidents at intersection i:

$$\lambda_i = \exp(\beta X_i + \varepsilon_i) \quad (2)$$

where,
X_i: the explanatory variables of intersection i; β: the coefficient of the explanatory variables ; ε_i: the gamma-disturbance term with mean 1 and variance $1/\theta$.

5. RESULTS AND CONCLUSIONS

The proposed model was estimated by the maximum likelihood method. The estimation results are shown in Table 1.

Table 1 Estimation Result of Negative Binomial Model

		Coefficient
Car traffic volume		3.69***
Intersection shape	Dummy of Cross Type Shape	4.85***
Left/right turn lanes	Dummy of All Arms Have Left/Right Turn Exclusive Lane	3.28**
Traffic signal	Dummy of All Arms Have Traffic Signal	-6.12***
Crosswalk	Dummy of No Arms Have Crosswalk With Bicycle Path	-1.10
Sidewalk	Dummy of All Arms Have Sidewalks with Guardrail Or Curbstone	2.98**
Parks	Dummy of intersections close to Shirokawa Park and Yaba Park	-0.25
	Dummy of intersections close to Hisaya-odori Park	-0.33
Spillover	Dummy of intersections next to the Fushimi and Sakura bicycle lanes	-1.46
Bicycle only lanes	Dummy of Fushimi and Sakura bicycle lanes	0.33
Over-dispersion		-3.99***
AIC		671.14
Sample size		173

*** significant at 95% level; ** significant at 90% level; * significant at 80% level

As shown by the result, car traffic volume has a positive effect on the occurrence of bicycle-related accidents; therefore, more cars result in more accidents involving bicycles. It is reasonable to assume that previously analyzed accident data showed that most bicycle-related accidents occurred between cars and bicycles: the more cars there were, the more bicycle accidents would have occurred. The intersection being cross-shaped, all arms having right- or left-turn exclusive lanes, and all arms having sidewalks with guardrails or curbstones were also positively related and significant. This can be explained by the fact that cross-type intersections have four directions and are generally large. Similarly, intersections with left- or right-turn-exclusive lanes and sidewalks with guardrails or curbstones are large and have more complex traffic flow than those without. At these large and complex intersections, there are many cars, motorcycles, bicycles, and pedestrians. The greater the number of traffic participants, the higher the probability of traffic accidents. Traffic signals have a negative effect, which means that having traffic signals for all arms helps control traffic flow at intersections to reduce the occurrence of bicycle-related crashes, especially with cars and pedestrians.

In conclusion, bicycle-related accidents occur more frequently when the car traffic volume is large, the intersection has a cross shape, all arms of the intersection have right- or left-turn exclusive lanes, and all arms of the intersection have sidewalks with guardrails or curbstones. Intersections with traffic signals in all arms reduce the occurrence of bicycle-related accidents. Having bicycle-only lanes does not appear to have a significant effect.

6. FUTURE WORKS

In this study, car traffic volume was considered in the model when estimating the risk factors. However, bicycle traffic volume was not included because of a lack of data. It is highly recommended to continue analyzing risk factors, including bicycle traffic volume. Moreover, injury severity is an important factor when analyzing bicycle accident risk. The authors will continue this study by considering factors affecting injury severity.

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