Analysis of Elderly Cyclists Behaviors and Conflict Risk at Signalized Intersections in Japan

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Abstract:
This study analyzed movements of bicycles and turning vehicles at signalized intersections through observation surveys in Japan and clarified the influence factors of dangerous conflicts and cyclists' safety check behaviors by statistical models considering the cyclist age. It is found that the setback distance of the outflow traffic affects not only the cyclists' safety check behaviors but also the occurrence of severe traffic conflicts between cyclists and turning vehicles at intersections in both elderly and nonelderly cyclists. It is also shown that there are some differences between elderly cyclists and nonelderly cyclists regarding the factors influencing severe traffic conflicts and their safety check behaviors. Furthermore, we discussed countermeasures for enhancing traffic safety based on sensitivity analyses.

Keywords: Elderly Cyclists, Traffic Safety, Signalized Intersection, Safety Check Behavior

1. INTRODUCTION

According to traffic accident statistics compiled by the National Police Agency (NPA) in Japan, the total number of traffic accidents has been gradually decreasing year by year and 3,904 fatal traffic accidents occurred in 2016 (NPA, 2017). It is noted that almost half of the traffic accidents had happened at or near intersections. The problem of traffic safety of persons crossing intersections is considered important in an aging society. Moreover, 20% of trips shorter than 5 km are made on bicycles. Hence, cycling is an important urban transport mode for most Japanese citizens. With the popularity of bicycles, research on cyclist behavior and bicycle facilities has naturally attracted a lot of attention in Japan. Recently, by looking at the success of European countries, the use of bicycle lanes or roads has been examined by local governments such as Tokyo Metropolitan Government and Fukuoka City Government. At the national level, a guideline for creating a safe and comfortable environment for bicyclists has been prepared by Ministry of Land, Infrastructure, Transport and Tourism and the NPA (MLIT, 2016). This guideline consists of a method of network formation, a design for basic section and intersection, rules for cyclists, and comprehensive countermeasures. Moreover, a design guideline for traffic operation at intersections has been prepared by Japan Society of Traffic Engineers (JSTE, 2015). Although some design guidelines have already been prepared in Japan, it is still necessary to analyze cyclist behavior in detail. On the other hand, many foreign researchers tried to evaluate traffic safety for cyclists at signalized intersections. For example, as for statistical modelling analyses, both cyclist activity and injury risk were evaluated by Bayesian modelling approach (Jillian, S et al., 2013). For risky behaviors at intersections, the factor of red-light running behavior was revealed by empirical analyses (Changxu,W. et al, 2012, Xiaobao, Y.et al.,2015). In addition, Level-of-Safety Service for Safety Performance Evaluation were discussed from the viewpoint of crash risk (Jian, L.et al.2008, Nordback, K. at al. 2015). As stated above, there are some researches about traffic safety for cyclists at signalized intersections, the accumulation of empirical research on the relationships among cyclist age, behaviors, traffic conflicts, and the external factors is not sufficient.

In this study, we focus on traffic conflicts between cyclists and turning vehicles at signalized intersections, analyze the factors influencing dangerous conflicts and cyclist behaviors, and discuss countermeasures for enhancing traffic safety through observation surveys. In particular, we compare behavioral characteristics of elderly cyclists and nonelderly cyclists near signalized crosswalks.

2. STUDY SITE AND DATA COLLECTION

Video camera surveys were conducted for several hours at three intersections including five crosswalks in the downtown area of Nagoya, Japan, with the purpose of analyzing the behaviors of cyclists and traffic conflicts. These intersections have witnessed several bicycle accidents over the last few years. The characteristics of survey sites are shown in Table 1 and the definition of intersection geometries are shown in Figure 1. The traffic signal cycle length is 160 s at the Nishi-Osu intersection, 140 s at the Heian-Dori intersection, and 150 s at the Nakagiri-cho intersection. The signal phase plans of the survey sites are shown in Figure 2. In addition, Japan follows left-hand traffic.

Table1 Characteristics of survey sites

	Length of crosswalk [m]	Angle of crossing roads [deg]	Number of lanes at outflow leg	Setback distance of stop line at inflow leg[m]	Setback distance of stop line at outflow leg[m]	Number of samples (elderly persons)
Nishi-Osu (East-leg)	22.0	105	3	20.5	21.1	249(48)
Nishi-Osu (North-leg)	34.0	75	3	14.6	22.1	221(42)
Heian-Dori (South-leg)	16.0	72	2	18.2	19.8	238(63)
Heian-Dori (West-leg)	23.0	94	3	17.4	18.8	107(30)
Nakagiri-cho(North-leg)	27.5	90	3	15.7	8.3	41(15)

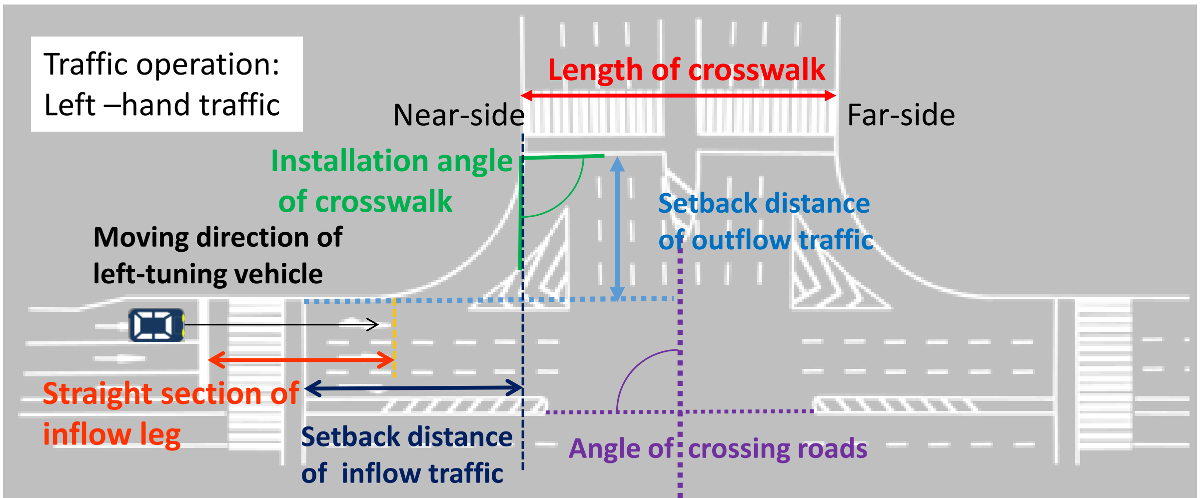

Figure 1 Definition of intersection geometries

N				Y		Y	AR				Y		Y	AR
Nishi-Osu	53	10	4	4	12	2	5	38	10	4	4	7	2	5
Heian-Dori	35	10	2	4	12	2	5	43	7	2	4	7	2	5

N				Y		Y	AR				Y	AR
Naka giri-cho	77	5	2	3	7	2	3	31	10	2	3	5

Vehicle green　Pedestrian green　Pedestrian Flashing signal

Unit: second, Y: Yellow time, AR: All red time

Figure 2 Signal phase plan of survey sites

In order to analyze video data, an image processing system developed by Suzuki et al (2006) was used in this study (Figure 3). This system can measure behavioral data such as vehicle and bicycle trajectories, speed, and traffic conflict index in 0.1 s intervals. And the accuracy of this system has been assured for the video images, which are recorded from a high altitude by Suzuki et al (2006). In this study, it was verified the accuracy of turning-vehicle speed, which drive in the 15km/h to 45km/h range, is nearly 1.0 km/h by comparison of measurement by the system and measurement by manual. On the other hand, as the result of the speed characteristics of cyclists for the two age-groups at three intersections is shown in Table 2. In addition, we specified whether or not the cyclist is an elderly person from the video image.

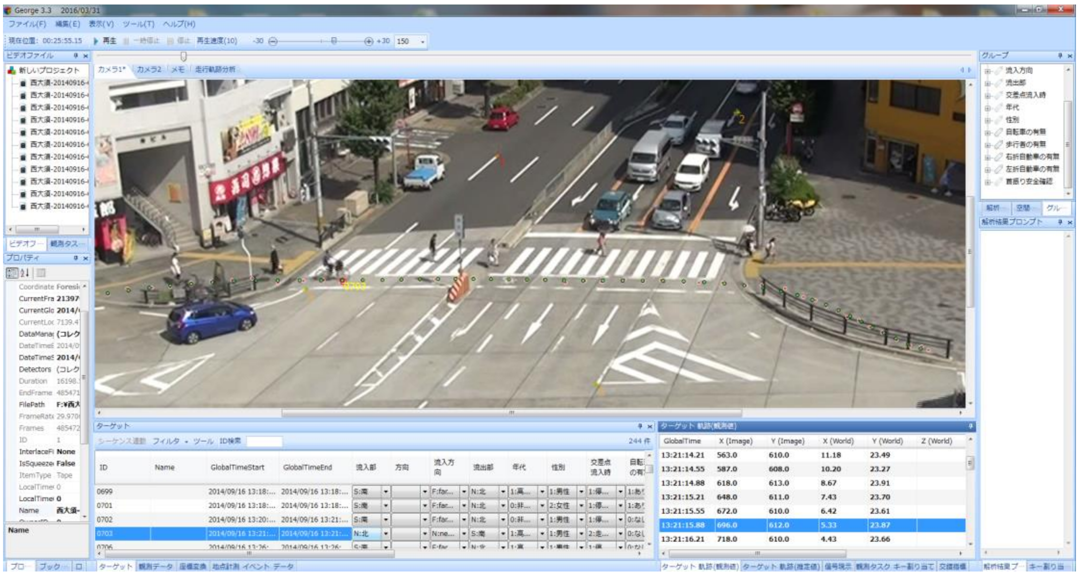

Figure 3 Screenshot of the video image processing system

Table 2 Speed characteristics for cyclists of each age group

Intersection	Age-group	Average [m/s]	Standard Deviation [m/s]	Coefficient of Variation	N
(a)Nishi-Osu	Elderly	2.53	1.06	0.42	90
	Non-elderly	2.93	1.33	0.46	371
(b)Heian-Dori	Elderly	2.30	0.93	0.40	92
	Non-elderly	2.59	1.30	0.50	250
(c)Nakagiri-cho	Elderly	2.27	0.98	0.43	15
	Non-elderly	2.68	0.95	0.35	26

3. ANALYSIS OF TRAFFIC CONFLICTS BETWEEN CYCLISTS AND TURNING VEHICLES AT SIGNALIZED INTERSECTIONS

3.1 Index of Evaluation of Traffic Conflicts

As an index to evaluate the traffic conflict risk between cyclists and turning vehicles at an intersection, the post-encroachment time (PET) index, which is defined by Allen et al (1978), is often used. When a cyclist and a left-turn or right-turn vehicle approach the crosswalk and their trajectories intersect on the crosswalk, the crossing point was as a conflict point. The time at which the former passes this conflict point was recorded as t1. The time at which the latter passes the conflict point was recorded as t2. The PET index is defined as the difference between t1 and t2.

3.2 Aggregate Analysis of Traffic conflicts

We focused on the case that a bicycle passes the conflict point before a turning vehicle and categorize the PET values into elderly and nonelderly data.

The distributions of PET values for each intersection are shown in Figure 4. The figure shows that the PET values of nonelderly cyclist conflicts are smaller than those of elderly cyclist conflicts at the Nishi-Osu intersection, whereas the Heian-Dori intersection data show a reverse trend. In addition, severe traffic conflicts are not seen at the Nakagiri-cho intersection.

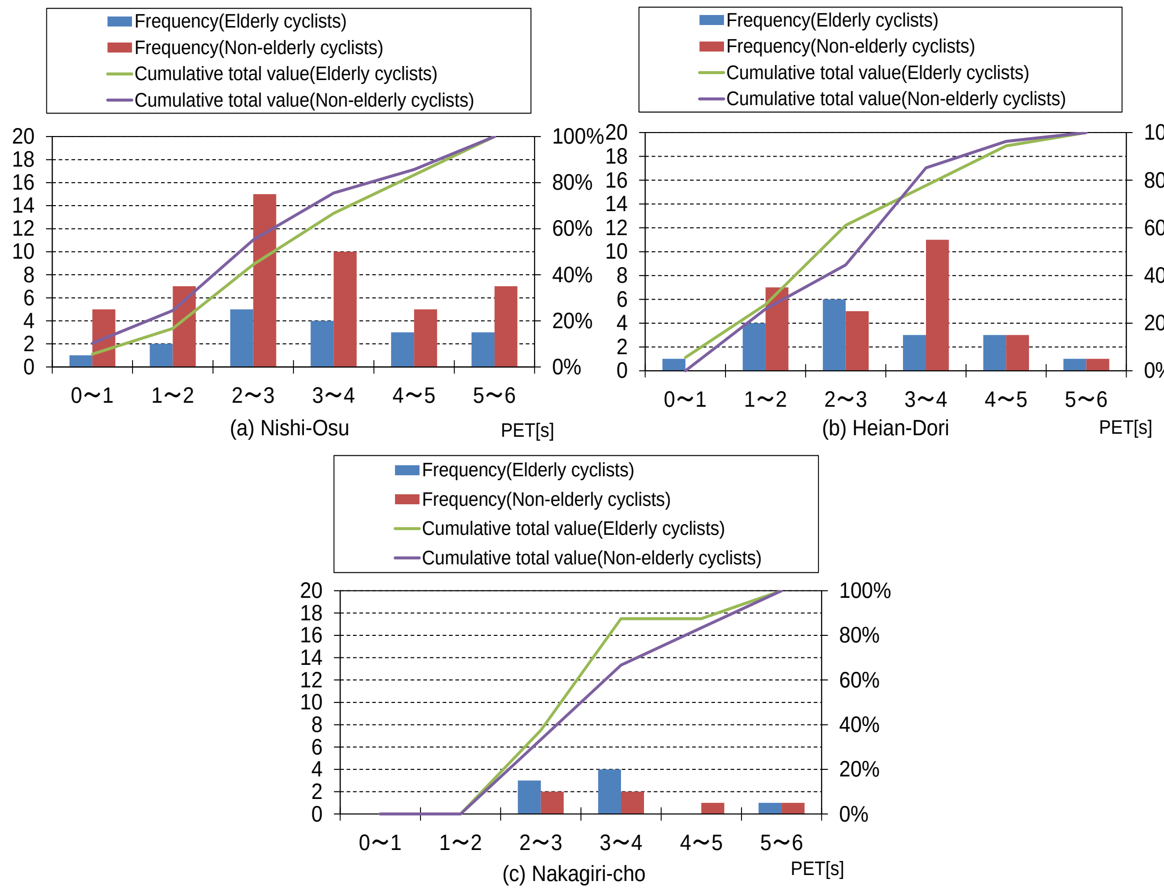

Figure 4 Distribution of PET values for each intersection

3.3 Statistical Analysis of Dangerous Conflicts of Cyclists at Intersections

We conducted a discriminant analysis using as a linear function shown in Equation 1 to clarify the effect of traffic conditions or road structures on the occurrence of dangerous traffic conflicts for both elderly and nonelderly cyclists. Here, we defined dangerous conflicts as situations with PET values ≤ 3 s with consideration for the size of the conflict area.

$$y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_i x_i \quad (1)$$

where y: discriminant score, b_0: constant, b_i: estimated coefficient for the explanatory variable x_i, x_i: explanatory variable.

Table 3 shows the parameter estimation result for the discriminant analysis. A negative sign for a coefficient means increase in that coefficient increases safety and a positive sign means increase in that coefficient increases risk (reduces safety). As the accuracy of judgment of dangerous conflicts for elderly cyclists is not sufficient, we need to improve the model by increasing the number of surveyed intersections.

Table 3 Parameter estimation result of discriminant analysis for dangerous conflicts (for elderly cyclists, level of significance (p): 0.579, hit ratio: 56.9%; for nonelderly cyclists, level of significance (p): 0.148, hit ratio: 65.8%)

Model / Explanatory Variable	Elderly bicycle users, N=53 (Dangerous conflict:15, Not dangerous conflict :38)		Non-elderly bicycle users N=111 (Dangerous conflict:24, Not dangerous conflict :87)	
	Standardized coefficient	Non-standardized coefficient	Standardized coefficient	Non-standardized coefficient
Dummy variable of Safety Check Behavior [if the cyclists did safety check behaviors at the edge of crosswalk when they enter the crosswalk :1, others:0]	-0.290	-0.750	0.912	1.960
Setback distance at inflow leg [m]	0.780	0.183	0.836	0.245
Setback distance at outflow leg [m]	-0.499	-0.231	-0.771	-0.468
Dummy variables of the existence of right turning vehicles [if there are some right turning vehicles when the cyclists enter the intersection: 1, others:0]	0.023	0.059	-	-
Dummy variable of the existence of other cyclists [if there are other cyclists who enter near-side edge of crosswalk :1 , others:0]	0.834	4.322	-	-
Length of crosswalk [m]	-	-	1.028	0.159
Dummy variable of heavy traffic [if there is a heavy vehicle near/at the conflict area:1 , others:0]	-	-	0.363	1.571
Constant	-	1.480	-	0.692

It is found that the setback distance of the inflow leg has a positive sign for both elderly and nonelderly cyclists, indicating that a longer setback distance of the inflow leg increases the risk to all cyclists. On the other hand, the setback distance of the outflow leg has a negative sign, indicating that a longer setback distance of the outflow leg increases cyclist safety. These results can be interpreted in terms of the ease of visual contact for the approaching vehicle. For elderly cyclists, both the existence of other cyclists and the existence of a right-turning vehicle are influence factors for a dangerous traffic conflict, whereas the safety check behavior (considered as a dummy variable) is the influence factor for a safer situation. Moreover, for nonelderly cyclists, both the dummy variable of heavy traffic and the length of crosswalk are influence factors for a dangerous traffic conflict. The results suggest that providing information to the elderly cyclists entering the near-side edge of a crosswalk by using image recognition technologies is an effective countermeasure to reduce severe traffic conflicts and this countermeasure is particularly useful when a right-turn vehicle is approaching the conflict area at the intersection.

4. ANALYSIS OF SAFETY CHECK BEHAVIORS OF CYCLISTS AT SIGNALIZED INTERSECTIONS

4.1 Definition of Safety Check Behavior of Cyclists

Next, we analyzed the safety check behavior of elderly cyclists at intersections by statistical analyses. We defined “rotating head for confirming the existence of turning vehicles at intersections” as a safety check behavior for cyclists, as shown in Figure 5.

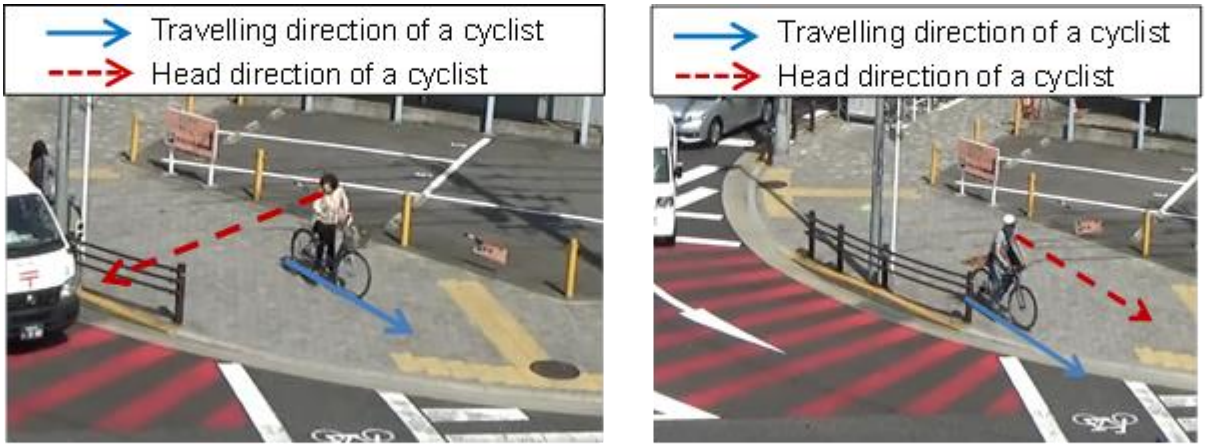

Figure 5 Safety check behavior of a cyclist entering an intersection
(left: with safety check behavior, right: without safety check behavior)

4.2 Analysis of Proportion of Safety Check Behaviors

We counted the number of safety check behaviors displayed by elderly/nonelderly cyclists and calculated the proportion of safety check behaviors with respect to the total number of cyclists at each intersection (Figure 6).

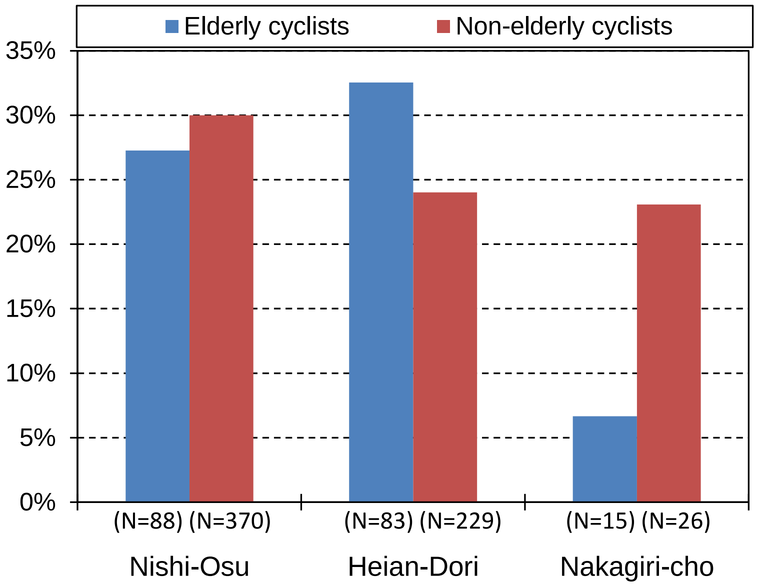

Figure 6 Proportion of safety check behavior of cyclists at each intersection

From the figure, the proportion of safety check behaviors of elderly cyclists at Nakagiri-cho is the lowest; on the other hand, the proportion of safety check behaviors of elderly cyclists at Heian-Dori is the highest. In addition, the proportion of safety check behaviors of nonelderly cyclists does not show a large difference from that of elderly cyclists at Nishi-Osu, but shows some differences at the other intersections.

4.3 Statistical Analysis of Safety Check Behaviors of Cyclists at Intersections

We quantified the influence factors of the safety check behaviors by discriminant analysis similar to the estimation of dangerous traffic conflicts. The result of parameter estimation is presented in Table 4. The negative sign indicates that larger values lead to no safety check behavior and the positive sign indicates that larger values lead to safety check behavior.

It is found that three explanatory variables, setback distance of the outflow leg, a dummy variable of red signal, and a dummy variable of entering near-side edge of the crosswalk, have positive signs for both groups. If the setback distance of the outflow leg is inappropriately long, it is difficult for the cyclists to confirm the existence of turning vehicles at the intersection. For the dummy variable of red signal, it is thought that the cyclists display the safety check behavior because the vehicles have the right of way. In addition, for the dummy variable of entering the near-side, the cyclists behave prudently because the distance between the cyclists and the turning vehicles is small in this situation. It is also shown that their velocities near the crosswalk relate to the safety check behavior. In addition, the angle of crossing the road has a negative sign; this means that if the angle of the crossing road is large, the cyclists do not check the surrounding traffic situation. Thus, it is thought that an obtuse angle intersection is unsafe for bicyclists and it is necessary to implement measures for supporting the safety check behaviors of cyclists. For example, a possible countermeasure is that the cyclists accept the cautionary information based on GPS data provided through a mobile phone when they approach an obtuse angle intersection. The results suggest that not only intersection geometries but also the entering timing and direction have an effect on the cyclists' safety check behaviors related to dangerous conflicts. For the safety of elderly bicyclists, providing information for encouraging the safety check behavior near an intersection using ITS technology is effective.

Table 4 Parameter estimation result of discriminant analysis for safety check behaviors (for elderly bicyclists, level of significance (p): 0.000, hit ratio: 75.1%;
for nonelderly bicyclists, level of significance (p): 0.000, hit ratio: 61.7%)

Model / Explanatory Variable	Elderly bicycle users, N=197 (with safety check:52, without safety check :145)		Non-elderly bicycle users, N=647 (with safety check:171, without safety check :476)	
	Standardized coefficient	Non-standardized coefficient	Standardized coefficient	Non-standardized coefficient
Dummy variable of entering near-side edge of crosswalk [if the cyclists entered from near-side edge of crosswalk: 1, others:0]	0.601	1.228	0.602	1.215
Dummy variable of the red signal [if the cyclists entered after starting red signal:1 ,others:0]	0.563	2.774	0.496	2.303
Setback distance of outflow traffic [m]	0.299	0.177	0.245	0.165
Angle of crossing roads [deg]	-0.413	-0.030	-0.424	-0.030
Dummy variables of left-turning vehicle [if there are some left turning vehicles when the cyclists enter the intersection: 1, others:0]	-0.301	-0.608	-	-
Dummy variables of slow speed[if the bicycle speed is range less than 1.0 meter per second: 1, others:0]	-0.197	-0.581	-	-
Dummy variable of medium speed [if the bicycle speed is in the range 3.0-4.0 meter per second: 1, others:0]	-	-	0.399	0.884
Constant	-	-1.331	-	-1.798

5. SENSITIVITY ANALYSES OF TRAFFIC CONFLICTS AND SAFETY CHECK BEHAVIORS AT SIGNALIZED INTERSECTIONS

By using the developed discriminant models shown in Table 3 and 4, we conducted sensitivity analyses. We focused on the effect of intersection geometry improvement on both the occurrence of severe traffic conflicts between cyclists and turning vehicles and the implementation of safety check behavior at intersections. Here, we chose the variable setback distance at the outflow leg, which is statistically significant in all models and change its value at 1-m intervals. In addition, we calculated the discriminant score for individual data using the traffic conflict discriminant model, judge whether each case is safe or not, and aggregate the proportion of severe traffic conflicts, divided into elderly and nonelderly cyclists. Moreover, the proportions of implementation of safety check behaviors were similarly obtained by safety check behavior discriminant models. These results are shown in Figure 7.

The figure shows that the larger the setback distance at the outflow leg, the safer the situation for all sensitivity analyses. The proportion of occurrence of severe traffic conflicts for elderly cyclists is down to 17% when the setback distance at the outflow leg is extended by 3.0 m. This means the severe traffic conflict risk is down by half compared with the current situation. It is found that the change of the setback distance for nonelderly cyclists has a much larger safety effectiveness. On the other hand, the proportion of implementation of safety check behaviors for elderly cyclists doubles compared with the current value when the setback distance at the outflow leg is lengthened by 2.0 m, whereas it remains unchanged when the distance is shortened by 1.0 m. In addition, the effect of lengthening the setback distance is gently increased in nonelderly cyclists than in elderly cyclists. It is also shown that the proportion remains unchanged from −2.0 to 1.0 m.

In order to realize a longer setback distance, it is necessary to set a longer red signal time because the setback distance is related to the setting of clearance time. There is a worry that this will lead to an increase in the number of vehicles running the red light and increase in high speed vehicles. However, we can adopt the z-crossing design to lessen the impact of geometry conversion as one of the countermeasure. It is also necessary to consider the convenience of pedestrians on the crosswalk at the same time. For example, Itoh et al (2016) revealed that it is more dangerous for pedestrians when the setback distance is longer. Therefore, the setback distance should be optimized for enhancing the safety of both pedestrians and cyclists at signalized intersections.

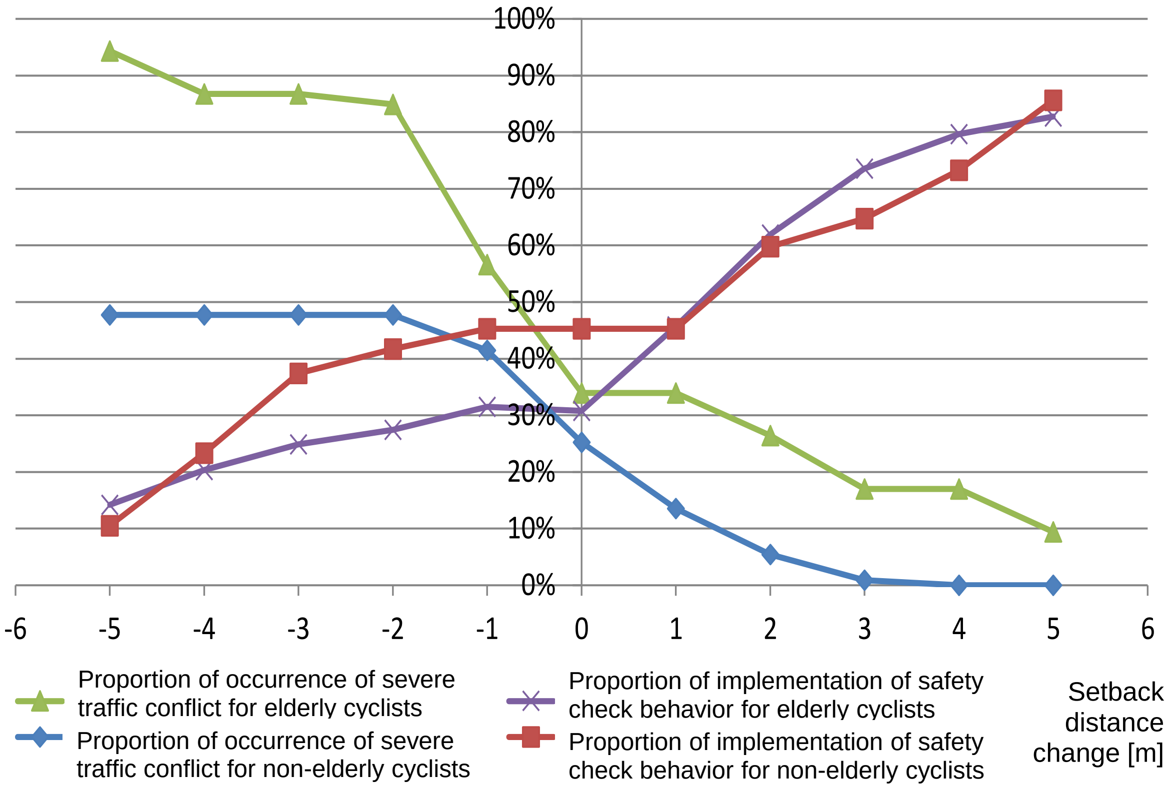

Figure 7 Results of sensitivity analyses of discriminant models

6. CONCLUSIONS

In this study, we analyzed movements of bicycles and turning vehicles at signalized intersections through observation surveys in Japan and clarified the influence factors of dangerous conflicts and cyclist behaviors by statistical analyses. It is revealed that intersection geometries such as the setback distance of the inflow/outflow leg have an effect on severe traffic conflicts between cyclists and turning vehicles, the approach direction of cyclists is also related to the occurrence of severe traffic conflicts, and the influence factors of elderly cyclists is different from that of nonelderly cyclists. In addition, we clarified the relationships among the safety check behaviors of cyclists near intersections, intersection geometries, and traffic situations. From these analyses, we proposed an improvement of intersection geometry to reduce the severity of traffic conflicts between cyclists and turning vehicles and increase the bicyclists' safety check behavior at signalized intersections. Here, some Asian countries are facing ageing society such as Thailand, Vietnam and there are some countries where have high modal split of bicycle and promote improvement of the bicycle travelling environments. In these countries, it is considered that they have troubles in the treatment of bicycle at the signalized intersections as well as Japan. Therefore, it is expected that this study achievements for the both discriminant models of conflict estimation and safety check behavior estimation are useful to discuss the improvement of intersection geometries, however it differs the traffic rule, manner and habitation from Japan to the other Asian countries. In addition, the number of elderly cyclists is not sufficient in our study; we need to improve this point by increasing the number of surveyed intersections. Furthermore, we need to validate the proposal from the viewpoint of pedestrian safety by using a microscopic traffic simulator. It is hoped that the results of this study are useful to enhance traffic safety at signalized intersections.

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