BEHAVIOR AND PERCEPTION ANALYSES ON EFFECT OF SEPARATED TRAFFIC SIGNAL CONTROL FOR PEDESTRIANS

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1. INTRODUCTION

About five thousand fatal traffic accidents occur in Japan every year. Although this number has been on the decline recently, the proportion of fatal accidents involving elderly people is increasing yearly and the percentage of fatal accidents involving pedestrians is also high. As for the site of the accidents, the National Police Agency (2009) reported that about half of the accidents occurred at intersections or near intersections.

Because of this situation, it is necessary to implement countermeasures to ensure pedestrians' safety at intersections. In several European countries such as Germany, key intersections are operated using a so-called group-based approach that traffic signal phase are set with the smoothness of each traffic movement in mind in order to reduce their delays. In addition, it reduces the effect of traffic conflicts between pedestrians and turning vehicles (FGSV, 2003). Although Tang et al. (2008) has shown the effect of this signal control, the system is rather new in Japan because of the complicated phasing plan. In recent years, in order to reduce traffic accidents in which cars turning right or left hit pedestrians crossing the intersection, separate traffic signals for pedestrians have been introduced, temporarily separating the right-of-way of pedestrians from that of turning vehicles, as shown in the manual of JSTE (2006). It is expected that this signal control system will significantly improve traffic safety because it removes the opportunities of traffic conflicts between vehicles and pedestrians in principle. However, this control results in longer waiting times than the unseparated-type traffic signal control, due to an increase in the number of exclusive phases during a limited cycle length. Therefore, there is concern that both a decrease in traffic efficiency and an increase in risky behavior, such as ignoring traffic lights, are induced by the longer waiting time.

Sasaki et al. (2002), researching this signal control system, evaluated the effectiveness of the system, which separates the right-of-way of pedestrians from that of vehicles by using a push-button signal. Their questionnaires and observations revealed that this system contributes to bringing a sense of ease for elderly people and children. Yoshida et al. (2003)

suggested that for traffic efficiency it is necessary to remove the impediments to the passage of right- or left-turning vehicles through an observation under the partially-separated traffic signal control. Suzuki et al. (2007) analyzed the effectiveness of this signal control at two and four lane intersections from the view point of vehicle behavior and revealed that unsafe vehicle behavior can cause a more dangerous situation than an unseparated traffic signal system. Few studies validate the utility of a separate traffic signal for pedestrians at large-scale intersections, though there have been several studies of this signal control at small-scale intersections with low traffic volume. Although in Suzuki et al. (2009), the author analyzed the effect of introducing this signal control to a six-lane intersection in view of the users' behavior, the parameter setting of traffic signal for reducing the risky behaviors and the temporal change in the effect of this signal control on uses' consciousness and behaviors are still not clear.

The objective of this study is to clarify the effect of installing separated traffic signal controls for pedestrians at large-scale intersections from the viewpoint of the users' consciousness and behaviors by conducting interview surveys and field observations via video cameras at multiple time points.

2. FIELD SURVEY FOR COLLECTING DATA ON USERS' BEHAVIORS AND CONSCIOUSNESS

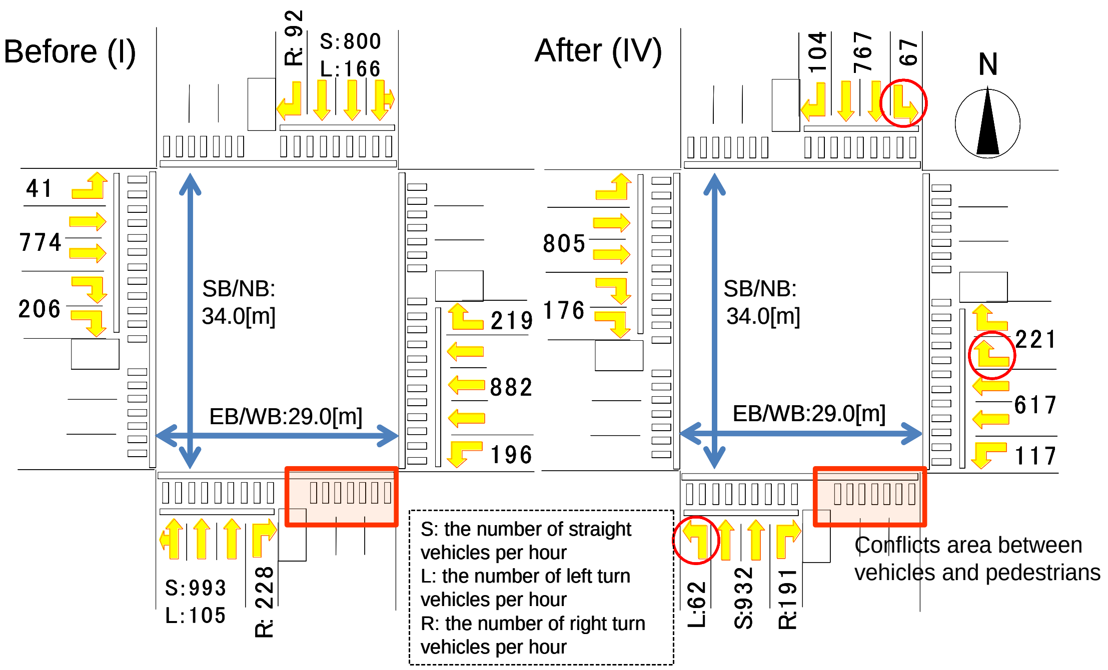
2.1 Characteristics of surveyed site

In order to analyze the effect of installing separated traffic signal control for pedestrians at large-scale intersections, data was collected at a signalized intersection, which is located in Nagoya city, Japan. This intersection has four legs as shown in Figure1. The east–west road has five lanes, and the north–south road has four lanes. This site, which has one of the highest accident rates in the prefecture, had 27 accidents in 2006. For this reason, separated traffic signals for pedestrians were newly introduced in September 2007.

Both the geometry of this site and the traffic volume during peak hours are shown in Figure1. Figure 1a shows the condition before introducing the separate traffic signal for pedestrians and Fig 1b illustrates the condition four months after introducing this signal control. This figure shows that the number of vehicles turning right and going straight per lane seems mostly unchanged on the whole, though the number of left-turning vehicles declined at some legs. In addition, part of the traffic volume was not measured due to a problem with the installation of a video camera recorder.

Figure 2 shows the phase plans of the surveyed site. From the figure, we see that after the changes to the signal system, the green signals for pedestrians and turning vehicles were divided during phi-1 and phi-5 and the green lights flashing for pedestrians and bicycle users were also separated. The green-light time for the southbound and westbound traffic was shortened from 42 s to 37 s and for the eastbound and westbound traffic it was also shortened from 54 s to 32 s.

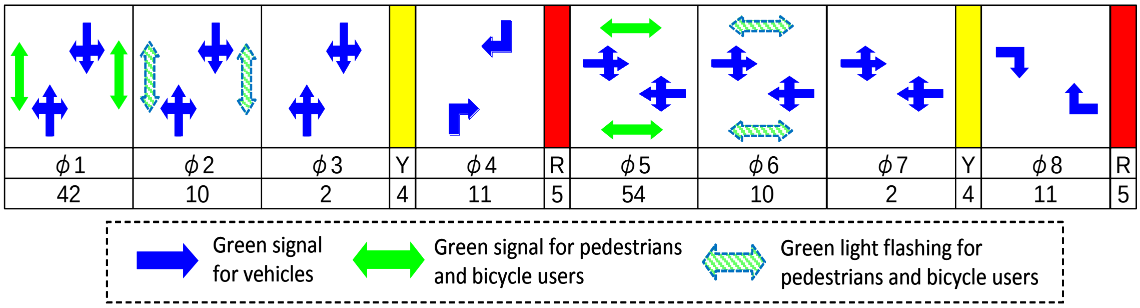
As a result, the split for the turning vehicles has been drastically shortened. Moreover, the lane utilization of the first lane on the south and north legs and that of the fourth lane of westbound traffic changed into an exclusive lane, as shown in Figure1b.



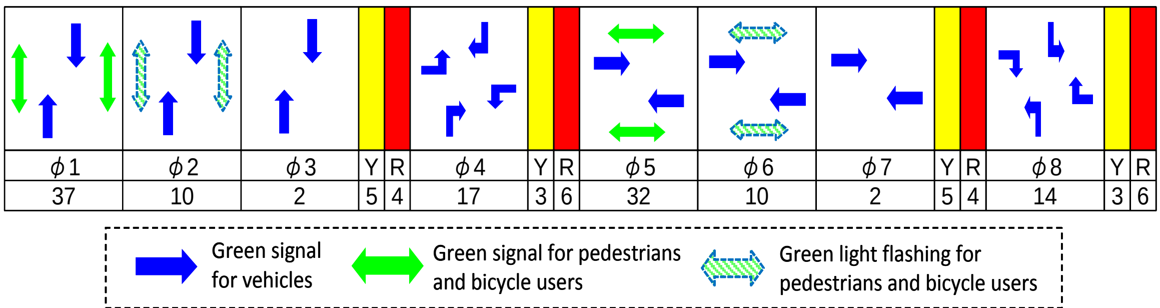
(a) Before introducing the separated traffic signal for pedestrians
(Traffic volume was measured at First survey (I))

(b) After introducing the separated traffic signal for pedestrians
(Traffic volume was measured at Fourth survey (IV))

Figure1 Geometry and traffic volume of surveyed site



(a) Before introducing the separated traffic signal for pedestrians (cycle length:160[s])



(b) After introducing the separated traffic signal for pedestrians (cycle length:160[s])

Figure2 Phase plans of surveyed site

2.2 Outline of interview surveys

Two interview surveys were conducted by interviewers around the intersection at different time points. Table 1 presents the outline of interview surveys and some of the attributes are shown in Figure 3, Figure 4, Figure 5 and Figure 6.

Though the sample size of these surveys was limited due to practical considerations of interviewing on the street, as shown in Table 1, it can be said that the data included a wide range of age groups and usage time as shown in Figures 3 and 4.

Figure 5 shows that in both surveys, almost 70% of the respondents used this site two or more times a week. Figure 6 illustrates that the proportion of bicycle users is the highest among all travel modes and also shows that there was more driving and less walking after the changes. Although there are some differences between the two surveys, as seen from these figures, it can be considered that there is not much difference between the attributes of the first survey and second survey.

Table 1 Contents of interview surveys

Items	Contents
Date	1st : mid-November, 2007 (one month after the signal control introduced) 2nd : end of February, 2008 (five months after the signal control introduced))
Method of survey	Interview surveys were conducted for pedestrians and bicycle users who waited for the next green signal near at the edge of crosswalk by investigators. The respondents were selected at random.
Sample size	1st survey: 84 2nd survey: 70
Collected data	(1) Attributes Age, Gender, Travel mode when he/she generally uses at this intersection, Usage frequency/time range, Composition of a family (whether he/she live with elderly person or not/ whether he/she live with under 15-year-olds or not) (2) Effect of installing separate traffic signals for pedestrian - Comprehensive evaluation for this signal control (both surveys) (Dissatisfied:1, Somewhat dissatisfied:2, Medium:3, Fairly satisfied:4, Satisfied:5) - Usefulness of this signal control for traffic safety (1st survey) (Not useful:1, not so useful:2, A little useful:3, Very useful:4) - Usefulness of this signal control for traffic congestion (1st survey) (Not useful:1, not so useful:2, A little useful:3, Very useful:4) - Whether this signal control has problems for traffic safety or not (2nd survey) (There is no problem:1, There are some problems:2, There are many problems:3) - Whether this signal control has problems for traffic congestion or not (2nd survey) (There is no problem:1, There are some problems:2, There are many problems:3) (3) Evaluation for the signal settings and the geometry of this site Cycle length (short or shortish:0, long or longish:1),Green time for commonly-used approach (short or shortish:0, long or longish:1), Green flashing time (short or shortish:0, long or longish:1), Yellow time for vehicle traffic(short or shortish:0, long or longish:1), Red time for commonly-used approach (short or shortish:0, long or longish:1), Length of crosswalk (short or shortish:0, long or longish:1)

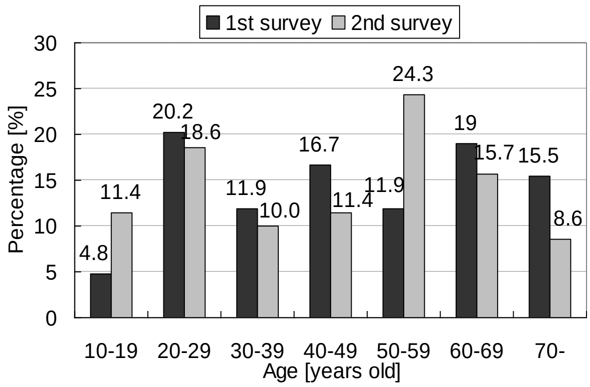


Figure 3 Age of respondents

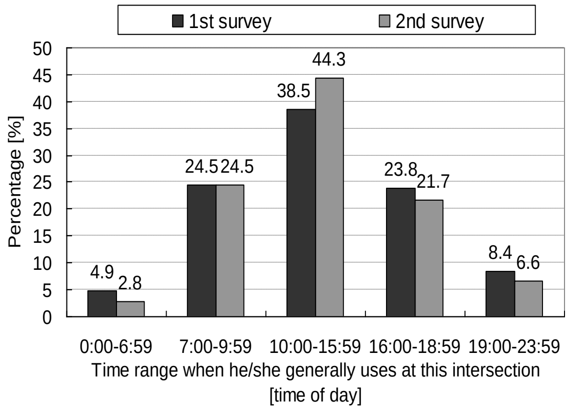


Figure 4 Time range when respondents generally use at this intersection

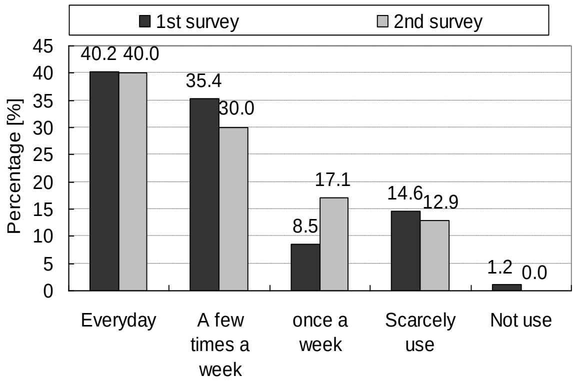


Figure 5 Usage frequency

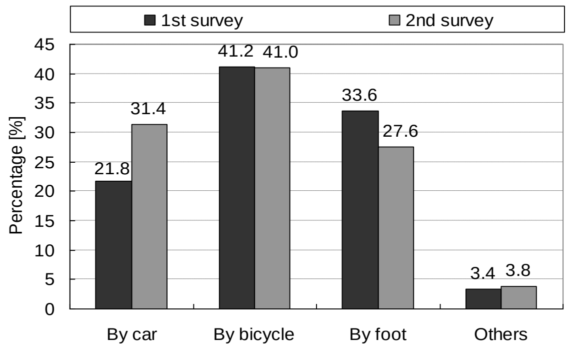


Figure 6 Travel modes when respondents generally use at this site

Table 2 Contents of field surveys via video camera recorders

Items	Contents
Date	I : end of July, 2007 (two months before the signal control introduced) II : early October, 2007 (after one week) III : early November, 2007 (after one month) IV : early February, 2008 (after four months) V : end of September, 2008 (after one year)
Time	8:00-9:00, 16:30-17:30
Method of survey	In order to collect users' behaviors, traffic signal parameters and traffic conflicts between pedestrian/bicycle users and turning vehicles, four or five video camera recorders were set near the intersection.

2.3 Outline of field surveys for collecting behavior data

Field surveys via video camera recorders were conducted at five time points as shown in Table 2. Each survey was set both during the morning peak hour and the evening peak hour. It focused on both pedestrians' behaviors and vehicle movements on the crosswalk at the south leg because this was the intersection in which the largest number of traffic accidents had occurred.

3. CONSCIOUSNESS ANALYSIS OF SEPARATED TRAFFIC SIGNAL FOR PEDESTRIANS

3.1 Immediate evaluations of introducing separated traffic signal for pedestrians

The users' consciousness regarding the new separated traffic signal controls for pedestrians in the first interview survey (one week after the changes were made) were analyzed. Figure 7 presents the survey results on the impact of this signal control on both traffic safety and traffic congestion for each travel mode. For traffic safety, over 80% of pedestrians and bicycle users recognized the usefulness of the introduction of this signal control system, and almost 70% of drivers also highly endorsed the system. Therefore, it is confirmed that from the traffic safety point of view, users of all travel modes highly supported the introduction of separated traffic signals for pedestrian in a large-scale intersection.

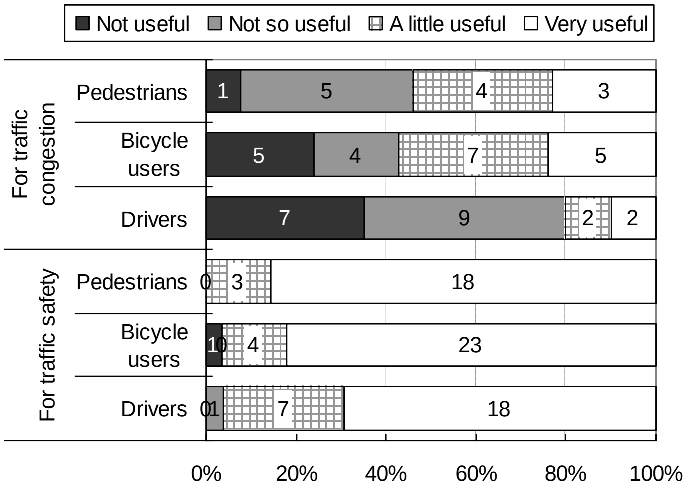


Figure7 Immediate evaluations for introducing this signal control

On the other hand, on the issue of traffic efficiency, almost half of the respondents of both pedestrians and bicycle users had a negative perception, and almost 80% of drivers also evaluated the system negatively. It is thought that this result is affected by the shortening the green light time, due to the separation of the right-of-way between pedestrians and turning vehicles, as shown in Figure 2.

3.2 Evaluations of introducing separated traffic signals for pedestrians after certain period of time

The second interview survey was designed to analyze the effect of the new signal control system after a certain period of time. Figure 8 shows the users' views on whether there are any problems for traffic safety and efficiency due to the new system.

Almost 30% of users recognized some problems for traffic safety and about 10% of drivers were aware of many safety problems, however, 70% of users evaluate this signal control as having no problems. That is, the awareness of problems that need to be solved has emerged after a certain period of time.

Meanwhile, about half of the users recognized problems of traffic congestion. In particular, 20% of drivers regarded this signal control as having many problems. Therefore, we may infer that appropriate signal parameter settings are needed in order to improve this situation.
In order to discuss these points in detail, the analysis of users' behaviors is discussed in the next section.

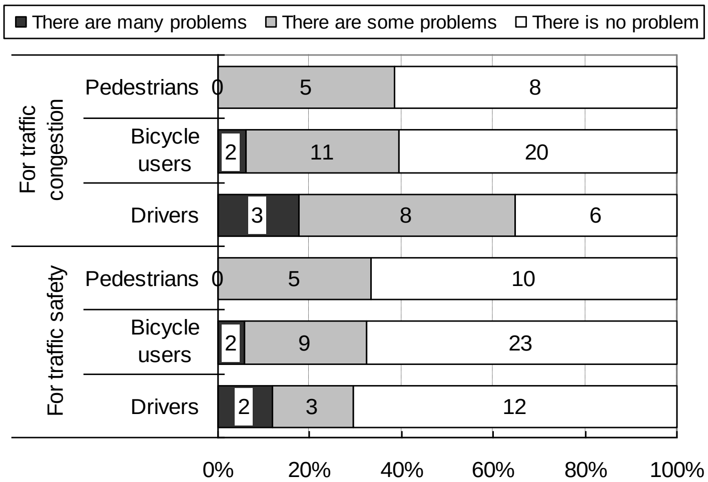


Figure 8 Evaluations for introducing this signal control after four months

3.3 Comprehensive evaluation of separated traffic signal control for pedestrians

3.3.1 Comparative analysis of comprehensive evaluation for two time points

This section discusses the comprehensive evaluation of the introduction of separated traffic signals for pedestrians. Table 3 shows the basic statistics of the comprehensive evaluation and the results of the t-test for the difference of the average value between the first survey and the second survey for each travel mode.
For the comprehensive evaluation of the first survey, the average values for all travel modes were over 4, indicating that the users' overall evaluation was "fairly satisfied". Therefore, the evaluation was positive immediately after the introduction of this signal control.
On the other hand, this table also shows that in the second survey, the average values of both drivers and pedestrians fell by about 1 point and that of bicycle users fell by 0.7 point compared to the first survey. In addition, Table 3 shows the statistically-significant difference of the average value between the first and second surveys for each travel mode using the t-test, as shown in Table 3.

Table 3 Basic statistics of comprehensive evaluation and test statistic for the difference of the average value for two surveys

Survey	Statistics	Mode		
		Drivers	Bicycle users	Pedestrians
1st	Average	4.08	4.31	4.50
	Standard Deviation	0.89	0.79	0.74
	Sample size	26	36	22
2nd	Average	3.12	3.65	3.63
	Standard Deviation	1.17	1.03	1.02
	Sample size	17	37	16
	T statistic	-2.98	-3.01	-2.97

* Significance level 5%

In the next section, we examine this result of the second survey which had low evaluations, by using the causal structural model.

3.3.2 Development of comprehensive evaluation model based on path analysis

It is clear from the analysis shown in section 2 that there is a declining trend in users' overall evaluation with time and different trends for the evaluation of both traffic safety and congestion according to the users' travel modes.

Thus, it clarifies the factors that influence the evaluation of traffic safety and traffic congestion, and analyzes the relationship between the evaluations for safety and efficiency and the overall evaluation. To reveal these users' evaluation structures, we apply path analysis to the data of the second interview survey in this study. Path analysis is based on multiple linear regression analysis and the structural equation model and can express the causal relationship and interrelationship among multiple variables with a path diagram (Greene, W.H. (2008)).

Table 4 presents the list of variables for using this analysis. In addition, Table 5 shows the definition of the variables for the adopted model, which is examined by the precision of the analysis, and Figure 9 shows the path diagram. In addition, path analysis can define the latent variables which are composed of several observed variables, and estimate the impact of the latent variables on the other observed variables, indirectly. It can also express the relationship between the observed variable and the other observed variables directly. However, it is revealed that this model does not include any latent variables as a result of accuracy validation of the analysis.

Table4 List of variables for using path analysis

Observed variables	(1) Attributes Age, Gender, Mode of transportation when he/she generally uses at this intersection, Usage frequency, Composition of a family (whether he/she live with elderly person or not/ whether he/she live with less than 15-year-olds or not), Usage time (2) Effect of installing separate traffic signals for pedestrian - Comprehensive evaluation for this signal control (Dissatisfied:1, Somewhat dissatisfied:2, Medium:3, Fairly satisfied:4, Satisfied:5) - Whether this signal control has problems for traffic safety or not (There is no problem:1, There are some problems:2, There are many problems:3) - Whether this signal control has problems for traffic congestion or not (There is no problem:1, There are some problems:2, There are many problems:3) (3) Evaluation for the signal settings and the geometry of this site Cycle length (short or shortish:0, long or longish:1),Green time for commonly-used approach (short or shortish:0, long or longish:1), Green flashing time (short or shortish:0, long or longish:1), Yellow time for vehicle traffic(short or shortish:0, long or longish:1), Red time for commonly-used approach (short or shortish:0, long or longish:1), Length of crosswalk (short or shortish:0, long or longish:1)

First, for the overall evaluation, we found that elderly users tend to give a highly positive evaluation for this signal control because the evaluation coefficient is positive. The evaluation value falls if the score of the responses regarding traffic safety problems or traffic congestion are high.

Table5 Definition of variables for the adopted model

Type of variables	Variable name	Definition of variable
Endogenous variable	Comprehensive evaluation	Comprehensive evaluation for this signal control (Dissatisfied:1, Somewhat dissatisfied:2, Medium:3, Fairly satisfied:4, Satisfied:5)
	Problem for traffic safety	Whether this signal control has problems for traffic safety or not (There is no problem:1, There are some problems:2, There are many problems:3)
	Problem for traffic congestion	Whether this signal control has problems for traffic congestion or not (There is no problem:1, There are some problems:2, There are many problems:3)
Exogenous variable	Elderly users	Dummy variable of their age (over 60's:1, others: 0)
	Live with less than 15 years old	Dummy variable of composition of their family (live with less than 15years old: 1, others: 0)
	Pedestrian (10am-4pm)	Dummy variable of time zone and mode (pedestrians when they use during 10am - 4pm: 1, others: 0)
	Drivers of high frequency used	Dummy variable of users (commonly-used travel mode is "driver": 1, others: 0)
	Time zone often used (0am–7am)	Dummy variable of time zone (users who often use this site during 0am to 7am: 1, others: 0)
	Long cycle length	Evaluation for cycle length of this intersection (short or shortish:0, long or longish:1)
	Long green time	Evaluation for green time for commonly-used phase (short or shortish:0, long or longish:1)
	Long the green flashing time	Evaluation for the green flashing time for commonly-used crosswalk(short or shortish:0, long or longish:1)

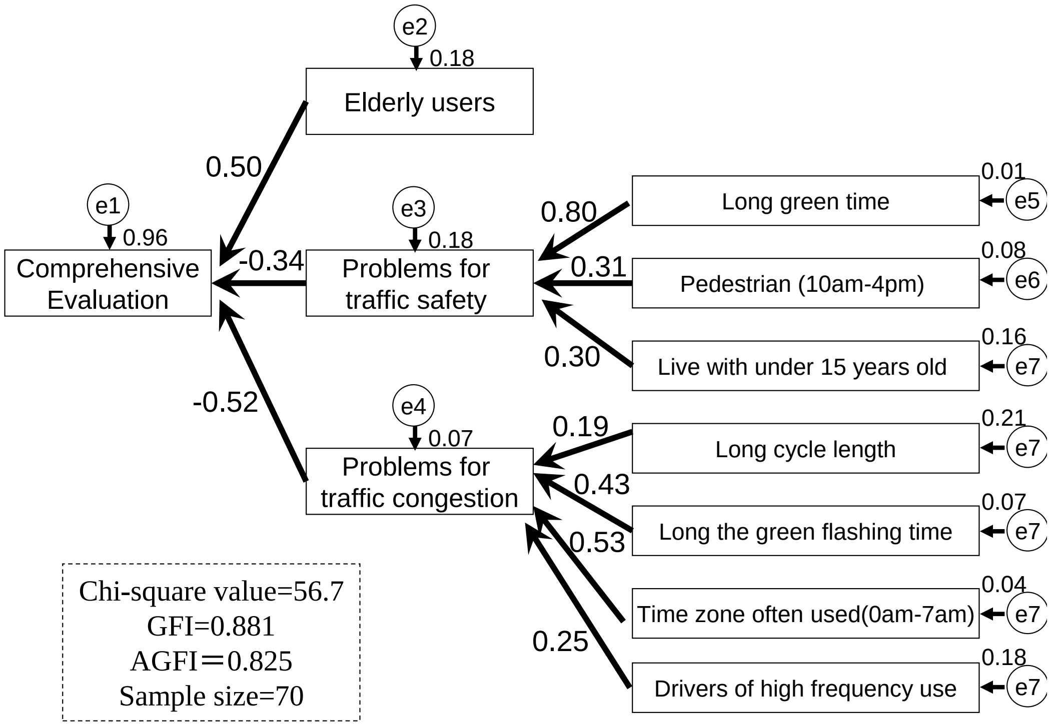


Figure9 Result of parameter estimation for path analysis
(Indicated value in this figure: standardized coefficient)

Second, it is shown that users who regard the green time at this intersection as inappropriately long see problems for traffic safety. Moreover, pedestrians who use the intersection during the daytime and users who live with children less than 15 years old increase the evaluation value of problem for traffic safety. By comparing the standardized coefficient of these three variables, we can see that the evaluation of the length of the green time has a significant impact on the evaluation of the problem of traffic safety.

Third, there are correlations between the variables for such traffic signal setting as the cycle length and the length of the green flashing time and the evaluation of traffic congestion. In addition, the respondents who use this site in the early morning and the drivers who use this intersection frequently see problems for traffic congestion.

As stated above, it was revealed those users' evaluation structures for separated traffic signals for pedestrians at this site. As a result, it leads to the suggestion that there is the necessity of resetting of the traffic signal parameters such as the cycle length and split in order to improve the overall evaluation of this signal control.

4. INFLUENCE EVALUATION OF INTRODUCING SEPERATED TRAFFIC SIGNAL FOR PEDESTRIANS BASED ON USERS BEHAVIOR ANALYSES

4.1 Analyses of entering time for each travel mode

4.1.1 Analysis of approach time for left -turning vehicles into conflict area

The area of the intersection where traffic conflicts between turning vehicles and pedestrians/bicycle users occur is on the pedestrian crossing. This section shows the result of the analysis of the left-turning vehicles' approach time into the conflict area, as shown in Figure1. Figure 10 presents the relationship between the approach time for left-turning

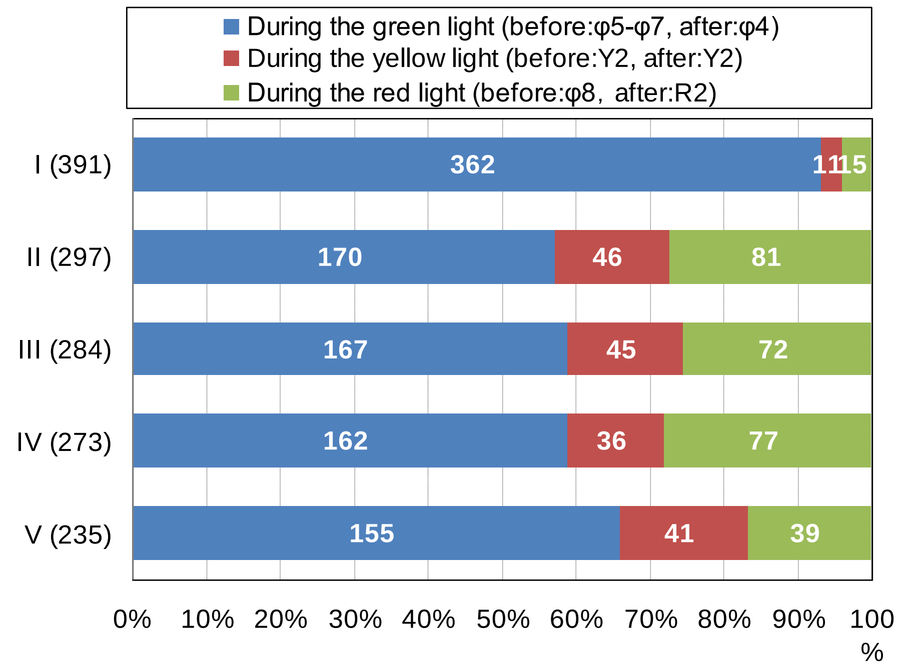


Figure 10 Relationship between the approach time for left turning vehicles and signal phase

vehicles and the signal phase at each surveyed date.

The proportion of the red-light running vehicles varies from 5% to about 30% after introducing the separate traffic signal for pedestrians. This risky behavior after the installation of this signal control induces a higher conflict risk because the next phase after phi-4 for the left-turning vehicles is the pedestrians crossing time, as shown in Figure 2.

As a result, the left-turning vehicles which are rushing into the intersection after the start of the red signal cause a risky traffic situation, though there is no traffic conflict between the turning vehicles and the pedestrians under this signal control in principle.

4.1.2 Analysis of entering time for pedestrians and bicycle users

We analyzed the arrival time at the edge of the crosswalk of both pedestrians and bicycle users by comparing the results of five time points as shown in Figure 11.

First, the proportion of the persons who cross immediately after the light turns green for both travel modes after the installation of this signal control are higher than before. This is because after introducing the separated traffic signal control for pedestrians, the red-light time was longer than before introducing this signal control, as shown in Figure 2, therefore, they are more likely to arrive at the crosswalk during the time of the red light.

Second, as for the rushing into the intersection after the green light starts flashing, the ex-post values are higher than the ex-ante values for both travel modes. This is influenced by the shortening of the pedestrian green time after introducing the signal control. The change is particularly prominent in the second survey, after which the value is fairly constant over time.

In addition, the proportion of people displaying risky behavior for bicycle users is higher than those of pedestrians. It is affected by the speed differences between pedestrians and bicycle users.

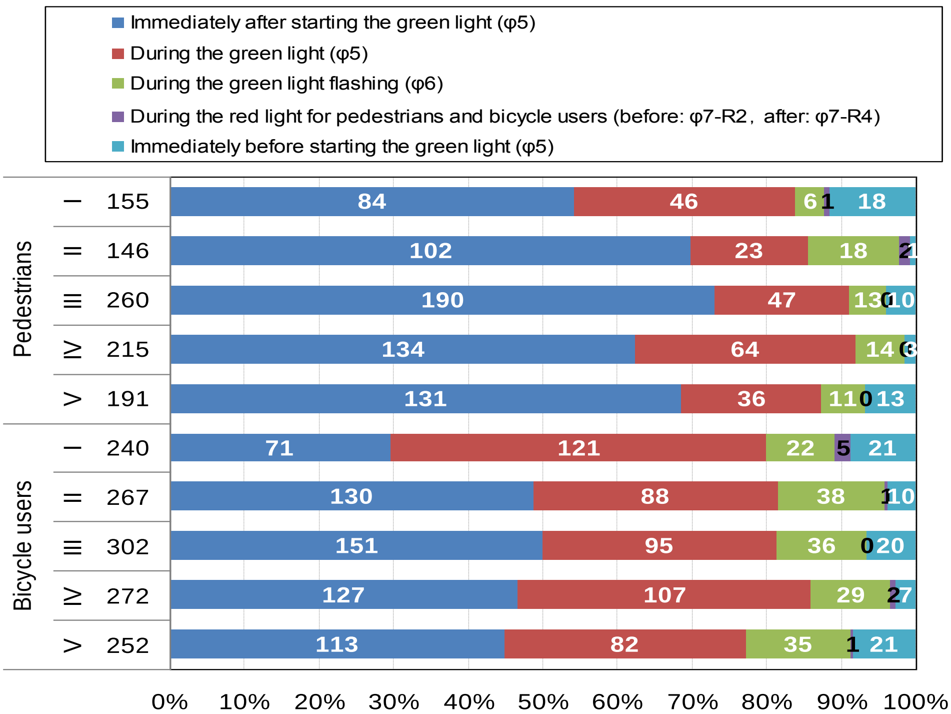


Figure11 Arrival time at the edge of crosswalk for pedestrians and bicycle users

On the other hand, as for the proportion of the persons who enter immediately before the light turns green, the values after the system change are lower than the values for both travel modes due to the existence of the left-turning vehicles which enter after the start of their red time.

4.2 Analysis of traffic conflicts between pedestrians and vehicle traffic

In this section, we discuss the possibilities of the occurrence of the traffic conflicts between pedestrians and vehicles by analyzing the results from before and after the changes. We focus on the difference between the two situations (before and after the system change) in the arrival times at the conflict points where the walking trajectories of pedestrians and turning vehicles cross on the pedestrian crossing. We use the index defined as Post Encroachment Time (hereafter called PET), which was devised by Allen et al. (1978) in order to evaluate traffic conflicts.
In view of the time required for a left-turning vehicle to pass through the intersection, a PET value within 6 s was measured as a conflict event. As for the traffic conflicts that occurred during the morning rush hour, Figure 12 shows the frequency distribution for ex-ante PET values, and Figure13 also presents the frequency distribution for the ex-post PET values at each surveyed time.

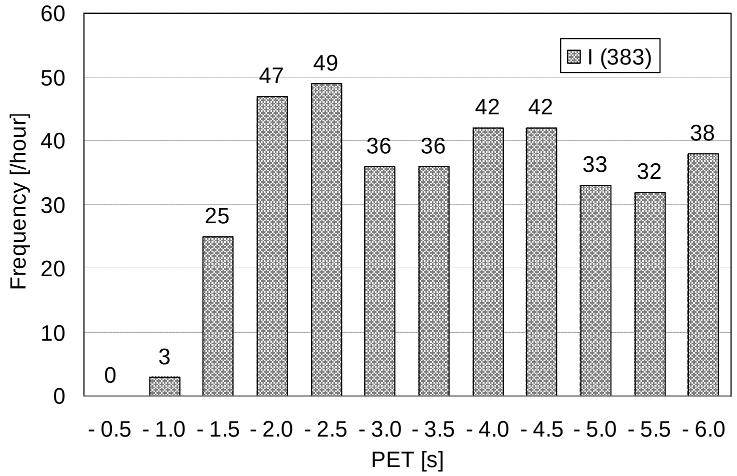


Figure12 Frequency distribution of traffic conflicts for ex-ante situation

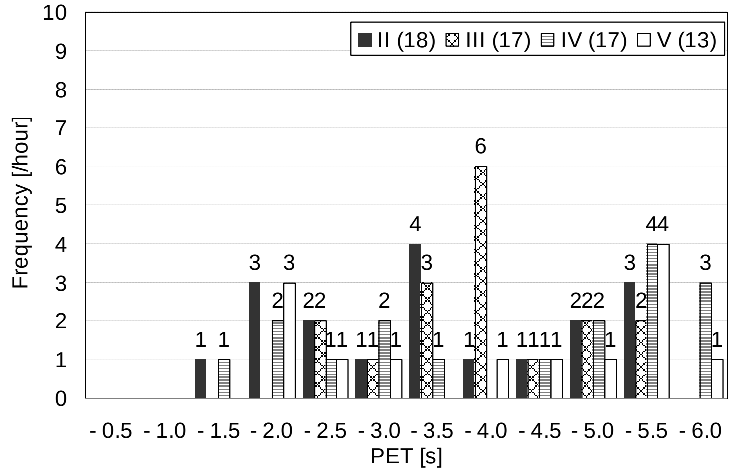


Figure13 Frequency distribution of traffic conflicts for ex-post situation

By comparing these two figures, we found that after introducing the separate traffic signal for pedestrians, the number of traffic conflicts within 6 s is about a twentieth of those of the ex-ante situation. That is, it is confirmed that traffic safety for this site showed a great improvement. However, it remains a critical issue that traffic conflicts still occur between vehicles and pedestrians/cyclists after the introduction, in spite of temporally-separating their right-of-ways. It is inferable that these traffic conflicts are influenced by the left-turning vehicles' risky behaviors of rushing into the intersection after their green time or the pedestrians who rush into the intersection after the green light flashing, as stated in the previous sections. Therefore, we analyze the pedestrians' risky behaviors after starting the green flashing time in the next section. In addition, we were unable to analyze the left-turning vehicles' behaviors described above due to the lack of upstream traffic situation.

4.3 Model analysis of risky behaviors after start of the green flashing time

Here, we focus our attention on the pedestrians' risky behaviors while rushing into the intersection after the green light has started flashing, in order to clarify the potential cause of traffic conflicts between left-turning vehicles and pedestrians at the intersections which are operated by separate traffic signal for pedestrians. The judgment of whether a pedestrian/cyclist takes such a risky behavior and ignores traffic signals or not, can be explained by a disaggregate binary logit model. The equations of probability and utility functions are shown below.

$$P_{pass} = \frac{\exp[u_{pass}]}{\exp[u_{pass}] + \exp[u_{stop}]} \tag{1}$$

$$u_{pass} = \alpha \cdot X_{con} + \beta \cdot X_{sig} + \gamma \cdot X_{arr} + \delta \cdot X_{att} + \cdots + \varepsilon \tag{2}$$

$$u_{\mathrm{stop}_k} = 0 \tag{3}$$

where:
P_{pass}: probability of passing intersection,
u_{pass}: utility of passage
u_{stop}: utility of stop
X_{con}: explanatory variables which are related to traffic conflict
X_{sig}: explanatory variables which are related to traffic signal setting
X_{arr}: explanatory variables which are related to arrival timing
X_{att}: explanatory variables which are related to users attributes
α, β, γ, δ, ε: parameters

This model analyzes the relationship between the judgments of risky behavior, the severity of the traffic conflict, the waiting time which is affected by the traffic signal setting, the arrival time, attributes, and so on. In addition, the model assumes that the severity of traffic conflict between the vehicles and the pedestrian/cyclist can be explained by the reciprocal of PET. Table 6 shows the results of the parameter estimation of the binary logit model. The judgments before introducing this signal control are explained by Model 1. On the other hand, the judgments after introducing this signal control are expressed by Model 2 and Model 3.

Table 6 Result of parameter estimation

Explanatory variables		Parameters (t-value)		
		Model.1 (Before)	Model.2 (After)	Model.3 (After)
Pass	Constants	-28.59 (-2.56)	-20.31 (-3.32)	-14.20 (2.61)
	Reciprocal of PET [1/sec]	-2.94 (-1.53)	-5.58 (-4.03)	-7.24 (-4.26)
	Waiting time for the traffic light to change [sec]	0.34 (2.73)	0.20 (3.78)	0.13 (2.95)
	Dummy variable of bicycle users [bicycle:1, pedestrian:0]	-3.09 (1.82)	0.99 (1.79)	-
	Dummy variable of westbound bicycle users [westbound bicycle user:1, other:0]	-	-	1.72 (2.59)
	Elapsed time between the start time of the green flashing and their arrival time [sec]	-	-	3.41 (2.38)
Sample size		40	233	233
Likelihood ratio		0.67	0.69	0.73
Hit ratio[%]		95.00	92.70	91.85

The accuracy of these three models is high enough, however some variables aren't statistically-significant.
For both the ex-ante and ex-post situation, the longer a user suffers the waiting time for the traffic light to change, the more likely he/she is to take risky behavior. The parameter of the reciprocal of PET is negative for the ex-post case, so it is found that the higher traffic conflict risk for the ex-post users affects their safety behavior. Meanwhile, the traffic conflict results for the ex-ante case is not statistically significant. This is because the ex-ante users have a greater tendency to experience the traffic conflicts than the ex-post users, so they are less aware of the conflict risk. And as for the result of the elapsed time, which is the time between the start of the green flashing and their arrival time, there is a tendency for pedestrians to make a risky judgment if they arrive at the edge of crosswalk after the green light has started flashing. Regarding the travel mode, it is shown that bicycle users are more prone to take risks than pedestrians, and especially the westbound traffic is likely to take risks by comparison with Model 2 and Model 3.

As a result, we believe that the following countermeasures should be considered for this site after introducing the separate traffic signal for pedestrians.

1. Improvement as by downsizing this intersection to reduce the PET value makes it easier for pedestrians and bicycle users to be sufficiently aware of traffic conflicts, and it produces a decrease in their risky behaviors after the green flashing time.

2. Reconsider the cycle length at this site to reduce waiting time.

3. Convey information warning of traffic conflicts after the green light to both pedestrians and bicycle users through the roadside facility.

5. CONCLUSIONS

In this study, we revealed that the effect of installing separated traffic signal controls for pedestrians at a large-scale intersection from the viewpoints of users' consciousness and behavior through interview surveys and field observations via video cameras at multiple time points. The conclusions of this paper can be summarized as follows.

1. It was found that both the evaluation for safety and overall evaluation were very high immediately after introducing this signal control, while the usefulness of separate-type traffic signals for traffic congestion was lowly evaluated. Moreover, it is also shown that the approval rate of the evaluations come down after a set period of time.

2. It was revealed that user attributes such as elderly users and high-frequency drivers and the variables of the traffic signal setting such as green-light time, green flashing time and cycle length have an impact on the users' evaluation of the separate signal control after a set period of time, as shown by the path analysis.

3. It was highlighted that the pedestrians' risky behavior – crossing after the start of the green flashing – which is related to the incidence of traffic conflicts, has increased, though the number of traffic conflicts between pedestrians and turning vehicles have reduced dramatically.

4. Through the model analysis, for the judgment whether pedestrian rush into intersection or not after the green flashing, it became clear that the waiting time at the lights affects their risky behaviors in the ex-ante situation, and both the traffic conflict risk and waiting time have an impact on the behaviors in the ex-post situation. As for travel mode, it is found that bicycle users tend to show risky behaviors.

As stated above, though the improvement effect for traffic safety by introducing the separate traffic signal for pedestrians into this surveyed site has been quantitatively analyzed, it is also revealed that such countermeasures as the resetting of traffic signal parameters, which are related to both users' evaluation and their risky behaviors, and geometry improvements for reducing the risky behaviors are needed in order to maintain high quality traffic environments at intersections. In addition, it will be useful to test applicable traffic conditions for introducing this separated traffic signal control by using a microscopic traffic simulation that can represent both pedestrians' behaviors and vehicles' movement.

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