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Implementation of Two-step Crossing System with Cycle-time Reduction: The Effects and Future Tasks

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Abstract: In Japan, and also in other Asian countries, intersections with very long signal cycle time have been problematic especially form pedestrian viewpoint. This research aims to suggest one technique to solve the problems: two-step crossing system with cycle time reduction, as a new standard of intersection design in Japan and other Asian countries as well. To check the effects of it, an experimental attempt are conducted in a real intersection and analyzed through a video survey and an interview survey. As a result, we revealed how much the effect differs by pedestrian walking direction and that lots of pedestrians accept this kind of experiment and think about the future extension. For future task, installing sound signals and remaining-time indicators, and applying different cycle time will be necessary to make this technique new Asian standard of intersection designing and controlling.

Key Words: *intersection design, signal control, pedestrian crosswalk, two-step crossing*

1. INTRODUCTION

1.1 Improvement Necessity in Large Intersection

As is often said, intersections have been one of the bottlenecks in terms of smooth traffic flow and traffic safety. In Japan, and also in other Asian countries, very long signal cycle times have been used especially in large intersection. One of the reasons is that it has been thought that applying long cycle time can allocate most of time to effective green time. This idea is partially true if looking just on traffic efficiency. However, under this long cycle time controlling, it is also true that once you are caught by a red light, you are forced to wait very long. Furthermore, if there are lots of turning vehicles, traffic flow rate must be affected by accumulating turning vehicles and may incur congestions. These phenomena may irritate drivers and make drivers aggressive. Consequently, traffic manners in lots of Asian countries are not so good. Here, what is more important is that in this situation we cannot secure safety and comfort for pedestrians. Pedestrians should also wait outside even when it is hot, rainy and cold. Therefore, we have to develop a technique to resolve those problems in large intersections from the viewpoint of not only vehicles but also pedestrians.

In Japan, they have noticed there facts and applied shorter cycle times and in present cycle times of approximately 120 or 140 seconds are often used, though it is still long comparing with European and American countries (Ieda and Hatoyama, 2001). However, in this situation another problem takes place in terms of pedestrian: lack of pedestrian green time in crosswalks. Under the short cycle time, abundant time cannot be allocated to pedestrian green time. Pedestrians have to rush often while crossing and keep crossing even after the signal turns red. Moreover elderly people cannot finish crossing in safe during green time.

This research aims to suggest one technique to solve those problems: two-step crossing system with cycle time reduction, as a new standard of intersection design in Japan and other Asian countries as well. To check the effects of this technique, an experimental attempt are conducted in a real intersection and analyzed through a video survey and an interview survey.

1.2 Two-step Crossing System with Cycle-time Reduction

Hatoyama and Kenzaki (2007) explained two-step crossing system as "a system that allows pedestrians to wait in the middle of crosswalks by equipping pedestrian refuges with signals for pedestrians". By installing this system, shorter cycle time can be applicable since it is basically enough to secure shorter pedestrian green time. One important point here is that in this system we should not design signal control so that all pedestrians have to stop at the middle of crosswalks and wait for the next green. The signal control should allow some pedestrians in faster walking speed to cross the street at once and should not force other pedestrians in slower speed, such as elderly, to do it but allow then to cross in two steps (Figure 1).

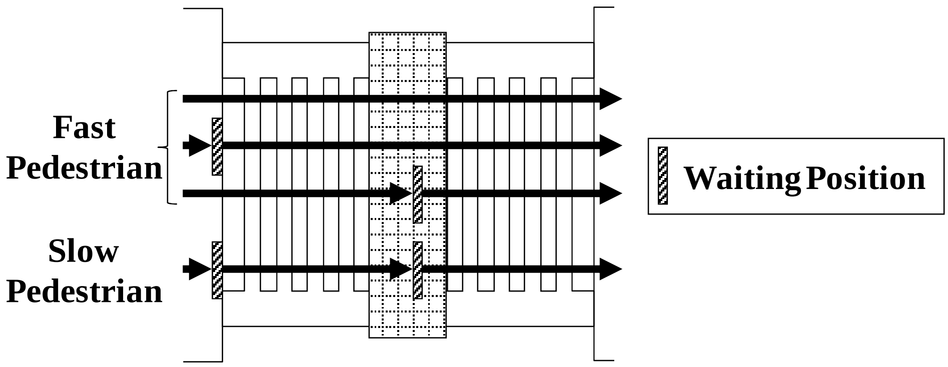

Figure 1 Walking speed and crossing patterns in two-step crossing system

To allow some pedestrians to cross at once in short cycle time, it is sometimes necessary to divide a pedestrian phase into two phases by a pedestrian refuge. This phase separation will provide more time to pedestrians to cross a part of the crosswalk if there is no traffic conflict (Figure 2). Moreover, Bacquie *et al.* (2001) pointed out that this technique can also contribute to pedestrian safety.

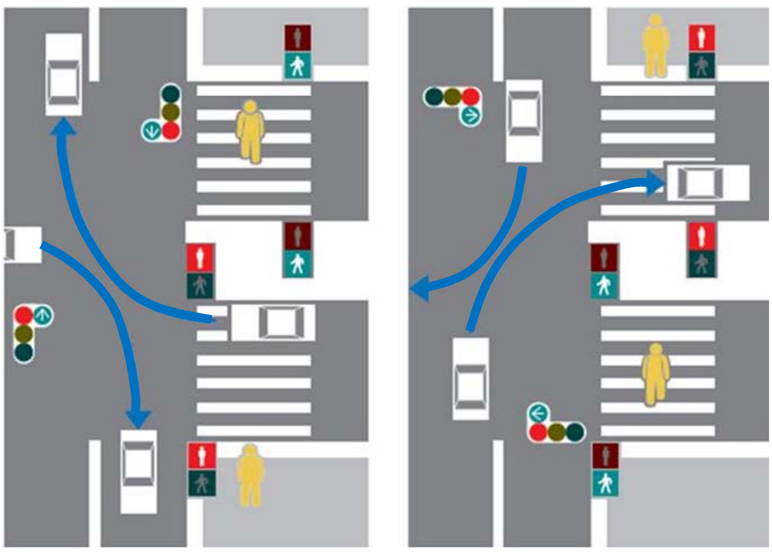

Figure 2 Pedestrian phase separation and green arrow for right turn

1.3 Previous Outcomes

To realize two-step crossing system with cycle-time reduction, it is necessary to know how to design not only physical structure but also signal control of the intersection. About the former, Hatoyama and Itabashi (2007) have suggested the level of service for pedestrian refuge design. About the latter, the effect of installing two-step crossing system with cycle-time reduction has been calculated by the traffic simulation model developed by Hatoyama and Kenzaki (2007). By combining the research about pedestrian refuge, this research also suggested the guideline for intersection design that is shown in Table 1. Here, a remaining-time indicator is a device attached beside a signal to inform remaining green or waiting time.

Table 1 Guideline for intersection design (Hatoyama and Kenzaki, 2007)

Crosswalk length or road width	Recommended cycle time	Recommended refuge structure	Remaining-time indicator	Split of secondary road	Phase separation
More than 28m/ 8 lanes	90 sec. (100 sec.)*1	3.5m or more width	Desirable to be equipped	0.3 or more	Unnecessary
				less than 0.3	Necessary
More than 19.5m/ 6 lanes	90 sec.	2.5m or more width with a guard fence	Unnecessary	0.3 or more	Unnecessary
				less than 0.3	Necessary
More than 15m/ 4 lanes	80 sec.	1.5m or more width with a guard fence*2	Unnecessary	0.3 or more	Unnecessary
				less than 0.3	Unnecessary
More than 5.5m/ 2 lanes	80 sec.	Unnecessary	-	-	-

*1 Cycle time can be 100 seconds without a remaining-time indicator.
*2 Some other devices than guard fences are needed to reduce pedestrians' feeling of fear.

In conducting an experiment in a real intersection, the experimental environment is designed based on this guideline.

1.4 Objectives of This Paper

The detailed objectives of this paper are as follows:

i. To check the effectiveness of two-step crossing system with cycle-time reduction in reality and
ii. To find out remaining tasks for the future application

In this paper, we lay emphasis on the viewpoint of pedestrian since it is more obvious that this technique can improve vehicle traffic than that it can improve pedestrian.

2. EXPERIMENTAL ENVIRONMENT

As mentioned above, we conducted an experiment in a real intersection. Here, where and how to conduct experiment is explained.

2.1 Experimental Site

As an experimental site, we chose a large intersection that is located in administrative district at the center of Tokyo. The name of the intersection is “Kasumigaseki ni-chome.” There are several reasons to select this intersection. First, the size of the intersection is appropriate. Since the two-step crossing system with cycle-time reduction is a new technique for large intersections, it is necessary to conduct an experiment in a large intersection, which is categorized in the first row of Table 1: “More than 28m/ 8 lanes”. However, if an intersection is so large to keep wide pedestrian refuges, such as an intersection under the overpass, it is obviously easy to realize this technique. The chosen intersection is counted as a large but not too large intersection where it is meaningful if the effectiveness would be checked. Second, for phase separation to allow pedestrians to cross smoothly in short cycle time, the signal of green arrow for right-turning vehicles is needed as is shown in Figure 2. To equip a new green arrow signal in an intersection, however, costs high and the procedure also takes too long time including asking opinions to Public Safety Commission of the region. Therefore, it is practical to choose an intersection where the signal of green arrow has already been equipped. Third, the district where the intersection is located is administrative district and the success of this experiment would be very influential on future expansion. That is to say, this intersection is academically, practically and strategically selected. Figure 3 shows the picture and the peak traffic flow of the intersection. The flow was counted by the traffic counters on October 19th, 2006 from 2:00 pm to 3:00 pm.

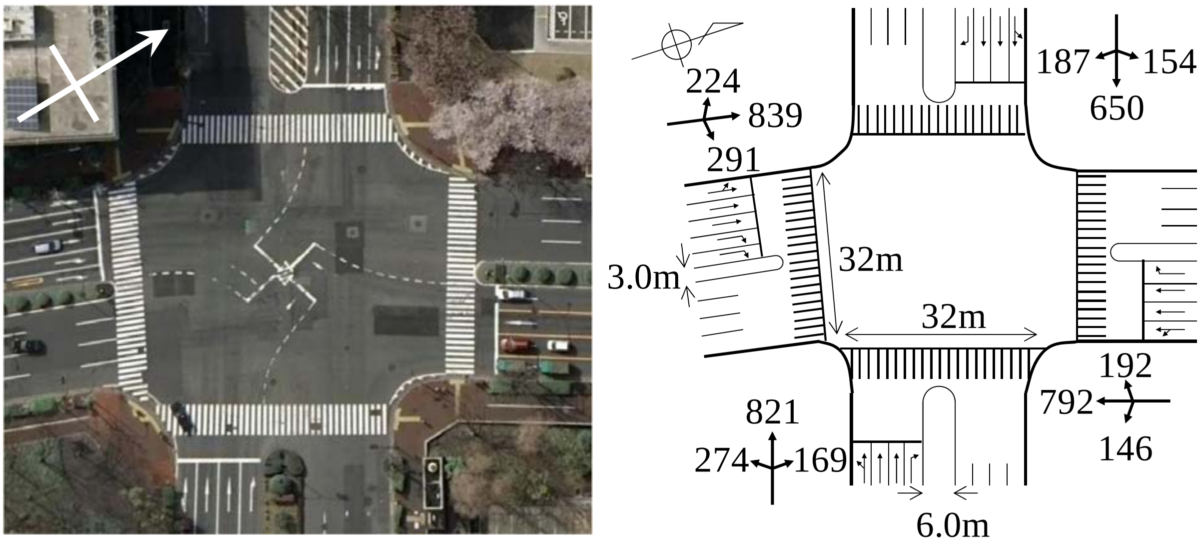

Figure 3 The picture of selected intersection and its peak traffic flow (Google, 2008)

2.2 Experimental Period

Experimental period was set during weekdays from January 13th, 2009 to February 13th, 2009 since the weather is usually stable to conduct surveys in this season in Japan and in weekend there are too few vehicles and pedestrians to observe.

2.3 Experimental Setting

2.3.1 Physical structure

Generally speaking it is pretty hard to change a physical structure of an intersection just for an experiment. However in the selected intersection a structure improvement reconstruction was planned and implemented by Tokyo National Road Administration Office as a pedestrian safety countermeasure. In this research we decided to utilize this opportunity for with-without comparison of the two-step crossing system with cycle-time reduction. In this reconstruction, they decided to extend the medial dividers and enlarge them so that they can make wide pedestrian refuges at the middle of each crosswalk. Each pedestrian refuge has a width of 5.5 meters with strong guard fences. According to the guideline shown in Table 1, it is not so necessary to equip guard fence. However, this facility will give us just a fail-safe condition and conducting an experiment under the better condition can be meaningful since this experiment is the first one in Japan; we must not fail in the experiment. The new physical structure and its image are illustrated in Figure 4.

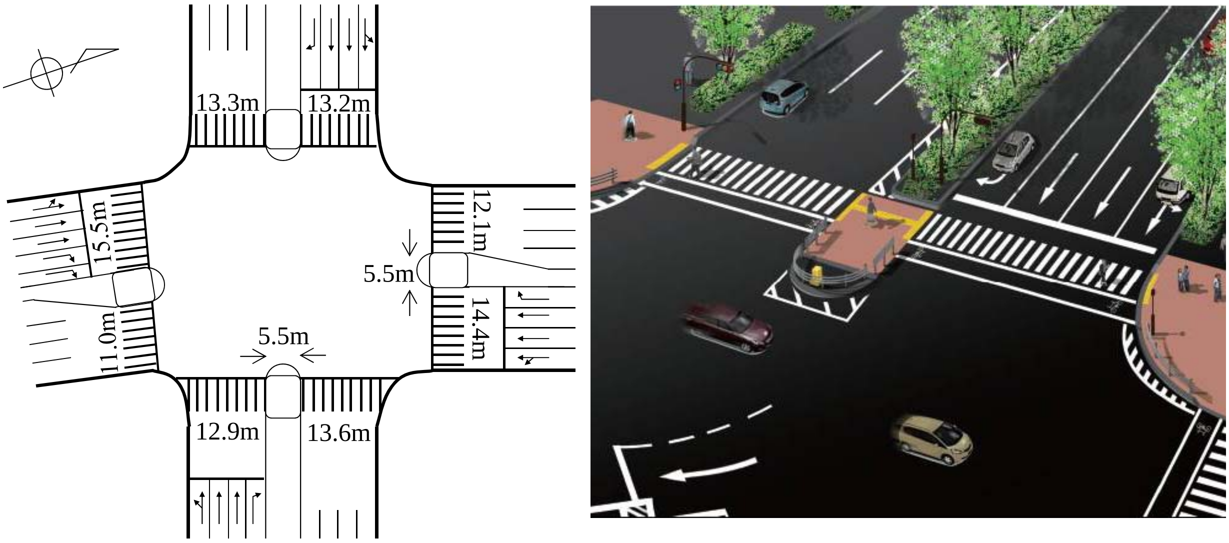

Figure 4 The new physical structure and its image

2.3.2 Signal phase setting

The typical signal phase which is usually used in the selected intersection is shown in Figure 5. The usual cycle time is set as approximately 140 seconds divided in four phases including a phase that gives right of way only to right-turning vehicles. During this phase, pedestrians of every direction are not allowed to cross. The cycle and split of this intersection is controlled dynamically based on real traffic volume.

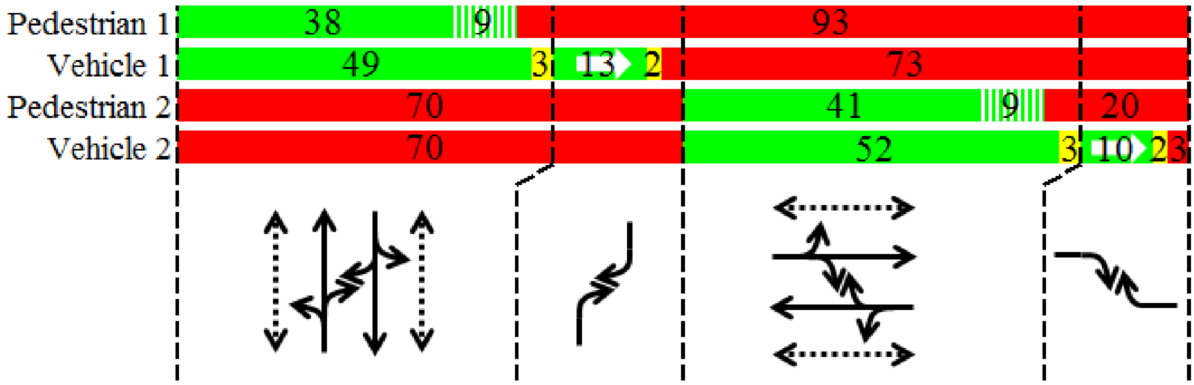

Figure 5 The usual signal phase of the intersection (Cycle time = 140 sec.)

Figure 6 shows the experimental signal phase that was applied during the experiment. The cycle time is set as 75 seconds. Here, when the signals allow vehicles to turn right, the phases give also right of way to pedestrians crossing sections where there is no traffic conflict. For example, the crosswalk “a” and “b” in Figure 6 are provided with 22-second (11 + 11) and 28-second (11 + 5 + 12) continuous green time. The signal phase is designed so that pedestrians walking clockwise do not have to wait long for green light. On the other hand pedestrians walking counterclockwise cannot enjoy the benefit very much. In conducting this phase setting, we have to take care of pedestrian’s misunderstanding in signal perception. In this setting, the signals at the pedestrian refuges and the ones at the end of the crosswalks are differently controlled. Therefore it might be dangerous if a pedestrian walks based on different signal. To avoid this behavior, we decided to equip shades on every signal at the end of the crosswalks so that a pedestrian cannot see the green light of the signal at the end until he/she reaches the pedestrian refuge. We also allocate traffic instructors at every pedestrian refuge. Figure 7 is a photograph taken during experiment where a traffic instructor is standing at the pedestrian refuge and the signal at the end of the crosswalk is invisible.

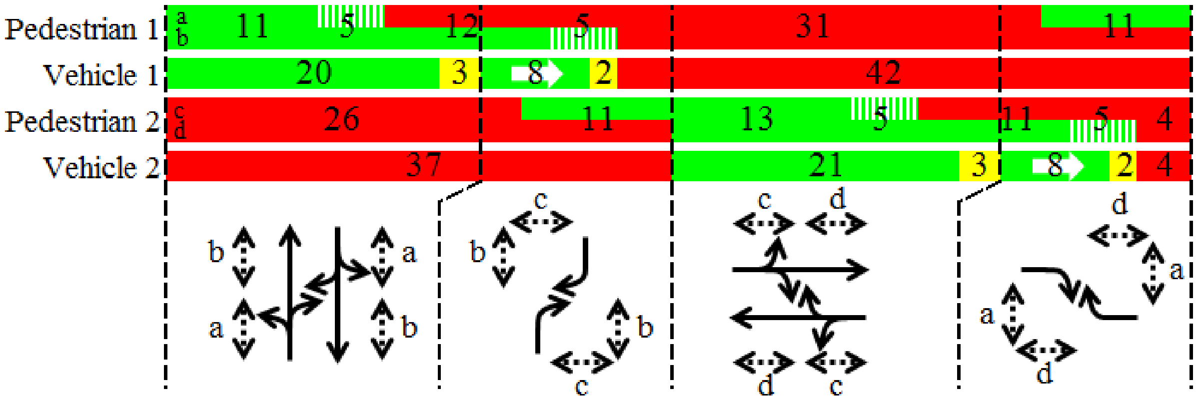

Figure 6 The experimental signal phase (Cycle time = 75 sec.)

Figure 7 A traffic instructor and a shaded signal at the end of the crosswalk

According to Table 1, a desired cycle time in this intersection are thought as 90 or 100 seconds. However, because of the existence of surrounding intersection, it is not practical to apply independent cycle time in the selected intersection. Actually, during the experiment, the cycle times of surrounding intersections were set as 150 seconds so that it can be easy to match these intersections and the selected one in terms of traffic flow.

2.4 Expected Effects

Based on the previous research, it is possible to mention the expected effects when installing two-step crossing system with cycle-time reduction. According to Hatoyama and Kenzaki (2007), if vehicles and pedestrians uniformly arrive at a large intersection like this one, the effects would be as follows (Table 2) in the case of cycle time change from 140 to 75 seconds. All factors were calculated as average values throughout a traffic simulation model called AIMSUN developed by Transport Simulation Systems (TSS). For calculating CO_2 emission, the CO_2 emission model proposed by Oguchi *et al.* (2002) was used in the model. It is obvious that the effect on pedestrians differs in relation to the direction to cross. Based on this research, the average waiting time shows a positive effect even for pedestrians walking counterclockwise. However, we should note that these values were calculated by assuming all pedestrians know the signal phase very well and behave rationally. The result might differ if lots of them do not get accustomed to the signal phase. Among these expected effects, pedestrian waiting time is mainly compared in this research.

Table 2 Expected effects of the experiment

Items	Cycle time = 140 sec.	Cycle time = 75 sec.
Vehicle waiting time	34 seconds	21 seconds
CO_2 emission	78 g-CO_2	68 g-CO_2
Pedestrian waiting time	26 seconds	5 seconds (CW) 20 seconds (CCW)

CW: clockwise, CCW: counterclockwise

3. SURVEY DESIGN

During this experiment, two types of survey were conducted: a video observation survey and an interview survey. Here, the details of them are explained.

3.1 Video survey

A video survey was conducted to measure movement of pedestrians. One survey was done on September 1st, 2008 from 12:00 pm to 1:00 pm as a preliminary survey and during the experiment it was done on January 14th and 20th from 12:00 pm to 12:30 pm. Because of the symmetrical property of the intersection, two crosswalks were chosen for this survey as is shown in Figure 8. To measure pedestrians' waiting time, pedestrian waiting areas were determined as yellow areas in Figure 8. Since pedestrians usually do not wait in a line in front of crosswalks like vehicles, we calculated pedestrians' waiting time by measuring time when a pedestrian enters into the waiting area and when finishes crossing. Altogether three video cameras were used; two were set on the 14th floor of the building at the south-east corner of the intersection, observing crosswalks each by each including pedestrian waiting areas; the rest was set on the ground of the same corner so as to observe signal change directly. The data was made by hand afterwards observing behavior of every pedestrian.

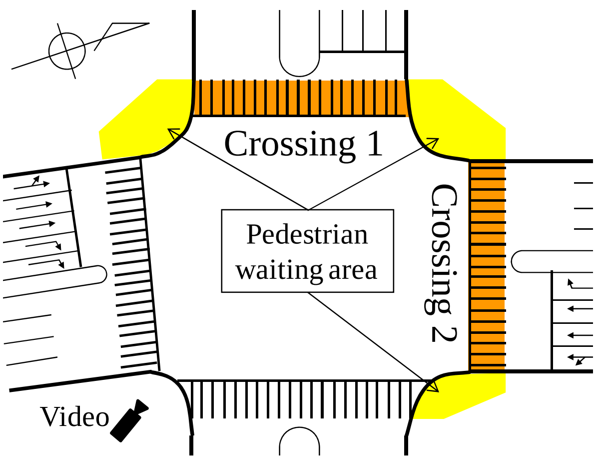

Figure 8 The determination of observed crosswalk and pedestrian waiting areas

In addition to measuring pedestrians' waiting time, we decided to check from this video survey what kinds of misunderstandings exist in installing two-step crossing system with cycle-time reduction.

3.2 Interview survey

To understand pedestrians' preference toward this technique, an interview survey was also conducted on January 19th, 2009 from 10:00 to 15:00 by four interviewers. Because this district is one of the busiest districts in Japan, we designed the set of questions as easy as possible so that an interviewer can finish his/her interview within 1 minute by walking together with an interviewee. The main questions to be asked are as follows:

1) How often do you use this intersection? Very often / Often / Sometimes / Rare
2) Did you wait for green light less than usual intersections? Yes / No / I don't know
3) Did you understand how to cross this intersection easily? Yes / No
4) Did you finish crossing without haste? Yes / No
5) Do you think this kind of new signal controlling technique should be applied to various intersections in the future? Yes / Relatively, yes / Relatively, no / No

We also asked interviewers to check the walking direction of each interviewee and whether he/she waited in the pedestrian refuge.

4. RESULTS

In this chapter, the results from two surveys are mentioned.

4.1 Effect on pedestrian waiting time

First of all, pedestrians' waiting time is considered. Here, other than their walking direction, pedestrians were categorized into two group based on their destinations. That is to say, for some pedestrians it is enough to cross only one crosswalk, but there are also pedestrians who have to cross two crosswalks to reach the cater-corner site (crossing 2 after crossing 1 or reverse direction in Figure 8). The former behavior is called "single crossing" and the latter "double crossing" in this paper.

Table 3 shows the average pedestrian waiting time before and during the experiment from the viewpoint of single crossing. For pedestrian walking counterclockwise, the waiting time includes both waiting time before crossing and also in the pedestrian refuge.

Table 3 Comparison of pedestrian waiting time (single crossing)

Date and direction		Sep. 1st	Jan. 14th		Jan. 20th	
		Preliminary	CW	CCW	CW	CCW
# of samples		446	64	130	78	93
Pedestrian waiting time (second)	Average	18.6	15.1	30.9	13.9	23.0
	SD	27.1	16.6	17.4	14.1	15.5
	Maximum	94.1	47.5	67.2	47.1	70.0

It is obvious that the waiting time of the pedestrians walking clockwise was drastically improved by this signal controlling technique although the average value is more than what was shown in Table 2. The reason is considered that the pedestrians were not yet accustomed to this new system and were not familiar with the signal phases. On the other hand, for those who moved counterclockwise it is not always time saving although the maximum value was improved. The main cause is the usage of the pedestrian refuges. Actually, 49% (on January 14th) and 37% (on 20th) of the pedestrians walking counterclockwise waited in the refuges while 0% in the opposite direction all the time. Moreover, the pedestrians in slower walking speed in this direction needed to wait twice: in front of the crosswalk and in the refuge.

However, the smaller standard deviations of all directions can help pedestrians estimate travel time easily. This can be counted as one of the merits of this technique.

Additionally, we should mention that the average waiting time on September 1st is much smaller than expected value in Table 2. This might be considered because the timings of green light in neighboring intersections were harmonized by chance and a bias in arrival distribution was generated. Although there exist some methodologies to eliminate this bias, we did not use adjusted data here to lay more emphasis on how much this system actually improved pedestrian convenience in this intersection.

Here, the average pedestrian waiting time from the viewpoint of double crossing is presented in Table 4.

Table 4 Comparison of pedestrian waiting time (double crossing)

Date and direction		Sep. 1st	Jan. 14th		Jan. 20th	
		Preliminary	CW	CCW	CW	CCW
# of samples		200	53	40	40	37
Pedestrian waiting time (second)	Average	27.2	2.4	68.6	2.5	67.1
	SD	18.0	9.2	39.9	8.0	36.7
	Maximum	83.0	64.4	152.5	30.4	114.1

For double crossing pedestrians, this signal controlling technique can also drastically reduce waiting time if walking clockwise. For counterclockwise movement, it is pretty inconvenient system as some of them needed to wait altogether three times. As a matter of fact, if a pedestrian needs double crossing, he/she doesn't have to walk counterclockwise since he/she can reach the same destination by walking clockwise. Therefore, when pedestrians get accustomed to this technique, they may choose appropriate way to cross and get not to choose counterclockwise way.

4.2 Pedestrian opinion

Second, the results of the interview survey are explained. The number of valid response was altogether 137.

4.2.1 Frequency of using the selected intersection

Figure 9 illustrates how often the interviewees use the intersection.

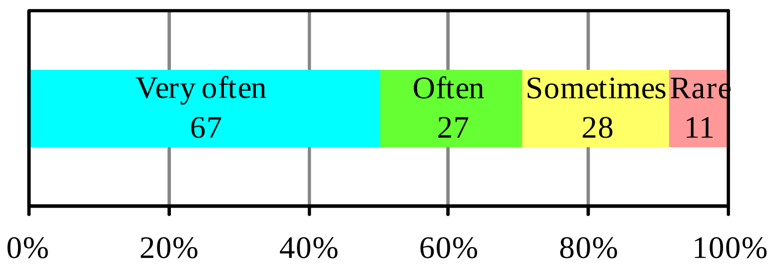

Figure 9 Frequency of using the intersection

According to this result, it is safe to say that we could collect opinions basically from frequent users throughout this interview survey.

4.2.2 Behavior of the pedestrians

Figure 10, 11 and 12 shows the behavior of the pedestrians; that is, the answers of "Did you wait for green light less than usual intersections?", "Did you understand how to cross this intersection easily?" and "Did you finish crossing without haste?"

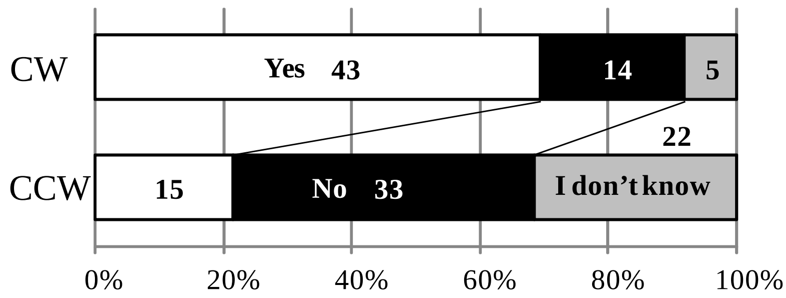

Figure 10 Answer of "Did you wait for green light less than usual intersections?"

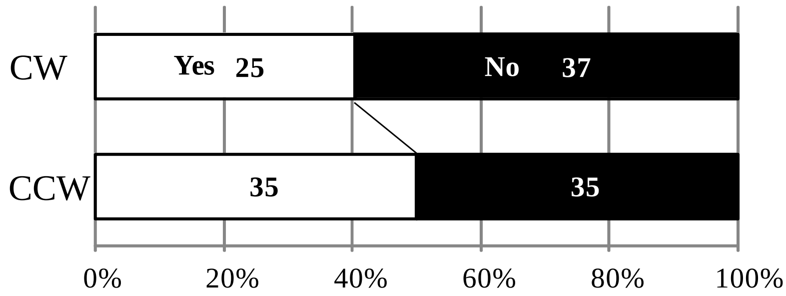

Figure 11 Answer of "Did you understand how to cross this intersection easily?"

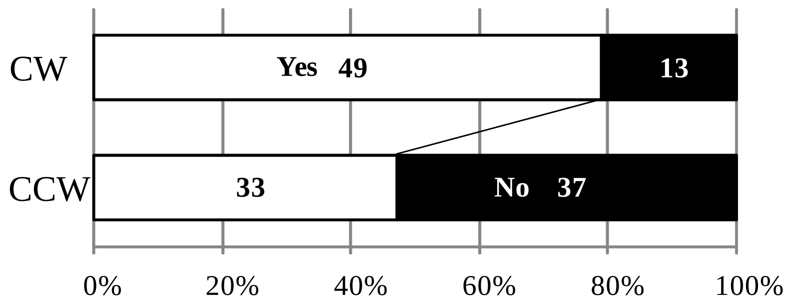

Figure 12 Answer of "Did you finish crossing without haste?"

From those results, it is safe to say that pedestrians walking clockwise feel comfortable in this system and that pedestrians of reverse dissection cannot feel free, which is fit together with the results about travel time and waiting time. Another indispensable point is that more than a half of pedestrians had trouble in understanding the signal operation.

4.2.3 Acceptance of the experiment

Since pedestrians walking counterclockwise cannot enjoy the benefit very much in this signal phase setting, it was easily assumed that they could not understand the significance of the two-step crossing system with cycle-time reduction. However, the result was slightly different. According to this result, it can be understood that most of pedestrians show positive attitude to change present situation and install any new technique like this experiment although not all pedestrians can get the benefit.

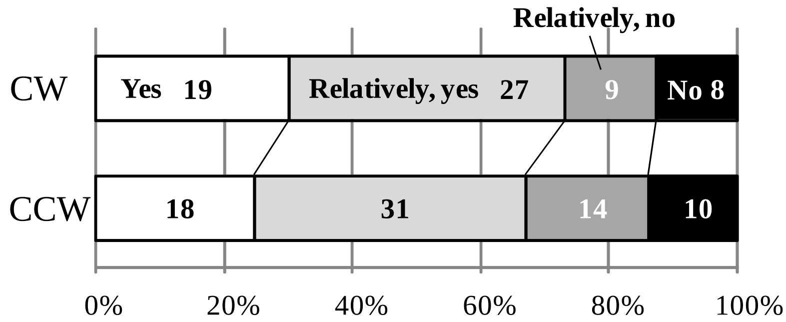

Figure 12 Answer of “Did you finish crossing without haste?”

4.3 Observed erroneous behavior

Finally, in this chapter typical behaviors observed from video survey are introduced which are caused by misunderstanding of the system.

- A pedestrian walking in clockwise direction started to run because his nearest signal was flashing and kept running even after the pedestrian refuge and reached the goal although he could reach there without rushing.
- A pedestrian did not start crossing although his nearest signal turned green because he saw some right-turning vehicles over the pedestrian refuge.
- A pedestrian walking in counterclockwise direction did not notice the red light after the pedestrian refuge and tried to keep going until the instructor said something to him.
- A taxi did not start to turn right despite right green arrow and the following vehicle honked a horn to make him notice the signal.

Some of them may be naturally resolved when users get accustomed to the system. However, it is also true that some other technique must be necessary to avoid those misunderstandings.

5. CONCLUSION AND FUTURE TASKS

In this paper, the new technique of two-step crossing system with cycle-time reduction was implemented at a real large intersection and conducted video survey and interview survey to check the effectiveness of this technique. As a matter of fact, it was revealed that the effect of this technique differs based on pedestrians’ walking direction; it is extremely convenient for clockwise movement; it is not so comfortable for counterclockwise movement. However, even so, it was found that lots of pedestrians accept this kind of experiment and think about the future extend. Therefore, on one hand, it is safe to say this experiment was successful.

On the other hand, several tasks are also remained in relation to this experiment. First, it is really important to think how to provide more information about signal phase. To allocate traffic instructors is one solution but it is obviously money-consuming. One way is installing sound signal into the intersection and providing information about when to start and when to stop. This equipment may also help visually-impaired people. Together with sound signal, remaining-time indicators must be equipped. Recently remaining-time indicators have become very popular all over the world and also in Japan a new type of pedestrian signal has standardized by National Police Agency (Figure 13). If those two equipments are installed in the intersection of two-step crossing system with short cycle-time, the most of the problems mentioned in section 4.3 would be immediately resolved.

Figure 13 A new pedestrian signal with remaining-time indicator

Finally, the cycle time used in this experiment is much shorter than proposed in previous research and almost all pedestrians crossing counterclockwise have to wait in the pedestrian refuge, which might irritate pedestrians. If there is an opportunity, cycle time of 90 or 100 seconds must be tested so that some of those pedestrians can finish crossing at once.

We are sure that this technique will give our Asian society a new standard of intersection designing and controlling.

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