Analysis on behaviours and safety of VRUs at unsignalized roadway crosswalk

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ABSTRACT

Pedestrian is the VRU in urban traffic system, especially along the motorization in city, the right-of-way of pedestrian was withered, along with the development of vehicles and the road net construction. And it is withering at present. At unsignlized roadway crosswalk, pedestrian is in a poorer situation for he/she has to watch, wait, grasp the rare gaps in the rapid vehicle flows, because drivers in Beijing are impatient for any delay on their way unless they meet a red signal.

In this article, two unsignalized crosswalks on roadway in Beijing are introduced. Based on statistic and observation, the behaviours and safety condition of pedestrian are described. Comparing the different traffic flow, the speeds on the roads and the gaps for pedestrian are analyzed, which are the basis for related study and the pedestrian walking situations. Speeds are measured according the types of pedestrian for study and compared with those in other conditions, which are an important parameter in behaviour analysis. Especially, not only the vehicle flow character, but also the number of pedestrians in platoon or crowds can influence the walking behaviours and safety condition. In observation, it shows that the waiting time influence the critical gap, not only the venturesome people can grasp the minor gaps. For pedestrians in a platoon or crowd can encourage each other. It results in the Game between the drivers and pedestrians, when they act in related tactic before they run into conflict area, according to the opposing parties, respectively. Gaps in vehicle flow can be enlarged by pedestrians indirectly, although it comes from vehicles directly. So the priority of right-of-way varies in different roadway, in light of the traffic condition and individuals who involved in the competition of right-of-way. The statistic of the data enriches related analysis based on observation and it useful for further research. Advices are provided for practice in engineering, and the conclusion can also be reference for similar measure.

INTRODUCTION

In developing countries, the road users are complex. Pedestrian is vulnerable road user in traffic system and quite a few of them are lack of knowledge on traffic rule. In China, the damage in traffic crashes is more serious than that in developed countries (1), thus pedestrian are more hazardous on road. Comparing the reason of crashes, pedestrian and bicyclist noncompliance occupied a 12.8 percentage in fatality crashes in Beijing. And about 70% fatality crashes are related to them (2).

In Beijing urban area, there are 867 crashes in total, with 753 injured and 220 fatalities, according to the record on crashes at intersection related to pedestrian, in 2003 and 2004. The average number of injured and fatalities is 0.87 and 0.25 respectively. It can also

support that pedestrian was the VRU, who need more consideration in design and traffic control. It will improve the safety level when pedestrian walking on road and efficient of traffic system that to make systemic researches on pedestrian behaviors and traffic characteristics, which is also useful for effective countermeasures against pedestrian injuries.

The unsignalized crosswalk is a conflict area between pedestrian and vehicles, where hazardous to pedestrian safety. The behaviors and traffic characteristics pedestrian walking across street are foundation for traffic design and management. In this paper, pedestrian behaviors at two unsignalized crosswalk were observed and measured from video and the data was compared.

The result of research will be the reference to improve the research on pedestrian characteristics at interrupted pedestrian facilities, which will be the elements of traffic safety audit and the related countermeasures as the guaranties on VRUs' improvement campaign.

CONDITION OF THE CROSSWALKS

The crosswalk in survey was at south gate and west gate of Beijing University of Technology (BJUT), respectively. They are both unsignalized crosswalk between two signalized intersections. Because of upstream traffic controls, vehicles arrival is discrete and continuous alternatively, according to upstream phases.

Crosswalk at south gate is named for A and another is B. Crosswalk A connect the campus of BJUT and some public attraction facilities along the south side of the street with midblock. The area of crosswalk and adjacent is narrow about 6m. But crosswalk B connects two zone of the university and the OD is directed linked by crosswalk B. Furthermore, crosswalk B is at a 1-part road with wider adjacent area more than 20m.

Figure 1 is the map of BJUT and figure 2 shows the photos of crosswalk.

Figure 1 The map of BJUT and location of the crosswalks in comparison.

Crosswalk A at south gate   Crosswalk B at west gate

Figure 2 The photographs of crosswalk A and Crosswalk B.

There will be more pedestrian at crosswalk B in peak hours (mostly from 9 to 10 am), for student walk across bi-direction for lessons and business trip in groups or crowd. Vehicle flows through the crosswalks are similar to each other, without upstream traffic jam. In recent years, there is a fatality crashes related to VRUs at each crosswalk area near the roadside respectively, with the similar reason of high vehicle speed and improper behavior when walk crossing.

Each single direction of vehicle traffic nearby the main campus of the roads are mainly analyzed and compared.

During the survey period, traffic volume of north road section (three lanes) is 698 vph (vehicles per hour) from east to west and the average vehicle speed is 38.9 km/h. It is 705 vph and 42.5 km/h at crosswalk B section northward (two lanes) respectively. And the volume of crossing pedestrian is 356 ped/h and 925 ped/h in spot A and B.

Table 1 Traffic condition of two compared spots

Road location	Through vehicle volume (vph)	Vehicle speed (km/h)	Crossing pedestrian volume (ped/h, bi-direction)
Crosswalk A area at south gate	698	38.9	356
Crosswalk B area at west gate	705	42.5	925*

*Bicycle riders are included.

Walking speed comparison

In observation, pedestrian at crosswalk consists of mostly adult and children and elders are not included. Bypass, it can be proved or deduced that at interrupted facilities the children and elder can also keep the speed with adult, at least temporarily, according some research results (3,4,5) and the observation of authors.

Based on the comparison of figure 3, the average speed at B is lower than that at A, which shows that the easier traffic environment at B. Like traffic calming management, the traffic condition makes drivers to slow down when they pass this road section, based on their experience, the site character, and groups of crossing pedestrians.
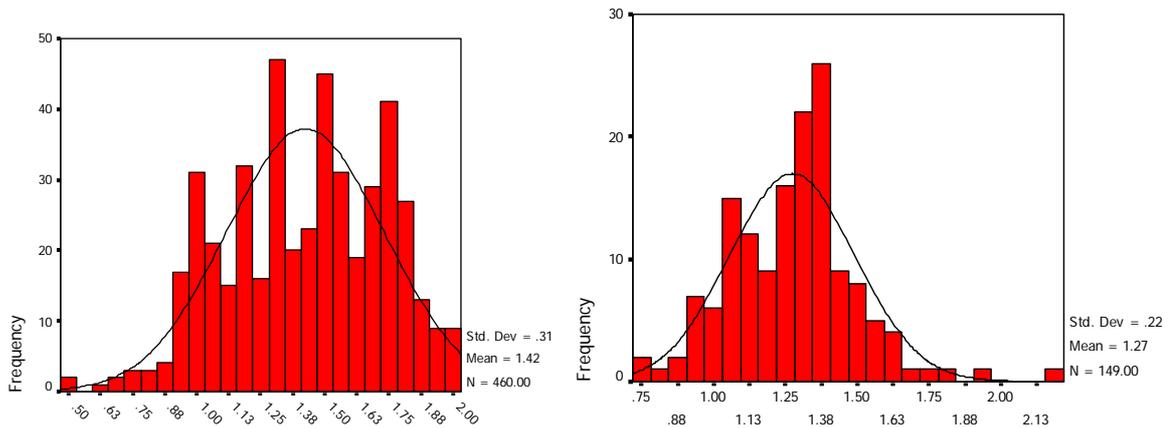
Figure 3 Histograms and normalized curve of pedestrian speeds at the two crosswalks.

Analysis on acceptable gap

There are three conditions when pedestrian walk across road (6):

1) Waiting for crossing opportunity. Only meets a sufficient gap for crossing or vehicle stops, should pedestrian walk;

2) Rushing walk. There is no sufficient gap in vehicle platoon, but pedestrian walk in a rush or run across road;

3) Meeting a sufficient when arrival and walking normally. When pedestrian arrives, there is a sufficient gap, so pedestrian walk through normally without waiting delay.

In the third condition, minor of pedestrian will use the whole headway as the gap, for they arrive at the time that a vehicle through just now. Major is that there is a lag between pedestrian arrival and vehicle left and the remained gap pedestrian used is still sufficient for walk through.

During the critical gap, vehicle can run through with original speed and pedestrian can finish walking through in common speed safely.

To discuss the accurate valid accept gap, the lag should be excluded. Actually, the critical gap of pedestrian walking across, is to discuss in which condition, most pedestrian will not refuse the valid gap to go and finish across at crosswalk.

At crosswalk A, pedestrian samples from north to south on north crosswalk (and adjacent area) are analyzed for critical gap. In statistic, the valid gaps pedestrian used are in the range from 3.81s to 34.89s and the refused gaps are in the range from 0.28s to 6.33s.

That means when pedestrian meet with the gaps in the range from 3.81s to 6.33s.

And at crosswalk B, it is from East to west. The valid gaps are in the range from 1.41 (observed value, probably the real value is lager than it) to 11.64 and the refused gaps are in the range from 0.344 to 6.812.

The decision on walk will fluctuate and drop into yes or not according to the gender, trip purpose, weather, temperature, and so on.

Figure 4 shows accumulative frequencies of samples of the two types above at crosswalk A. In the figure, the upper blue diamond dots are the samples of acceptable gaps and the lower pink rotund dots are the refused gaps. There is a flat section when gaps near to 10s and in the range from 10s to 15s with 50th percentile accumulative frequency, there is a leap in the trend. When the gaps become longer, more and more pedestrian will accept them, for the main of the observed gaps result from vehicle arrival and there is no difference on decision for different pedestrian. Only short gaps show the personal decision influence on gaps choice. Refer to related researches (7, 8 and 9), in this paper, the samples were selected with the threshold 12s. With regression curves and equations of revised accept gaps and refused gaps (See figure 5)), the critical gap can be obtained according to the solution. Then

it can draw a conclusion on gaps, that the critical gap is 4.8s in the crosswalk when pedestrian walk across (10). And the accumulative frequency is about 8%. It means that about 8% of the pedestrian will make ambiguous decision, for the traffic condition is clear for pedestrian.
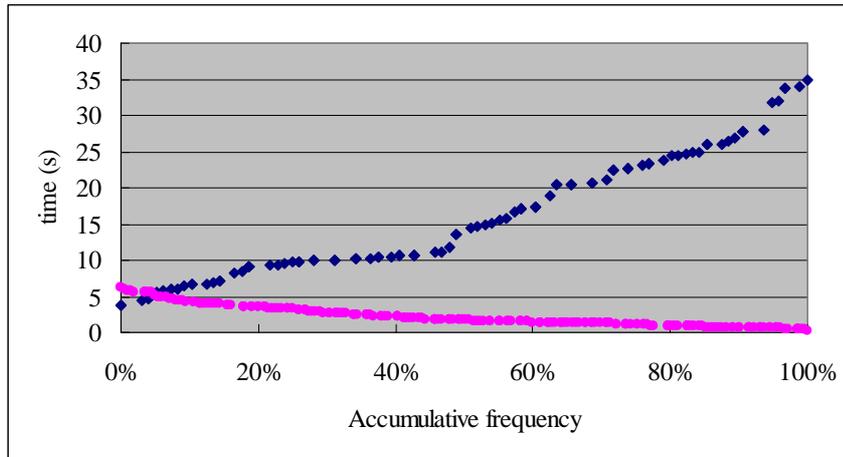

Figure 4   Scatter dots of pedestrian accepted and refused gaps (All data at crosswalk A).
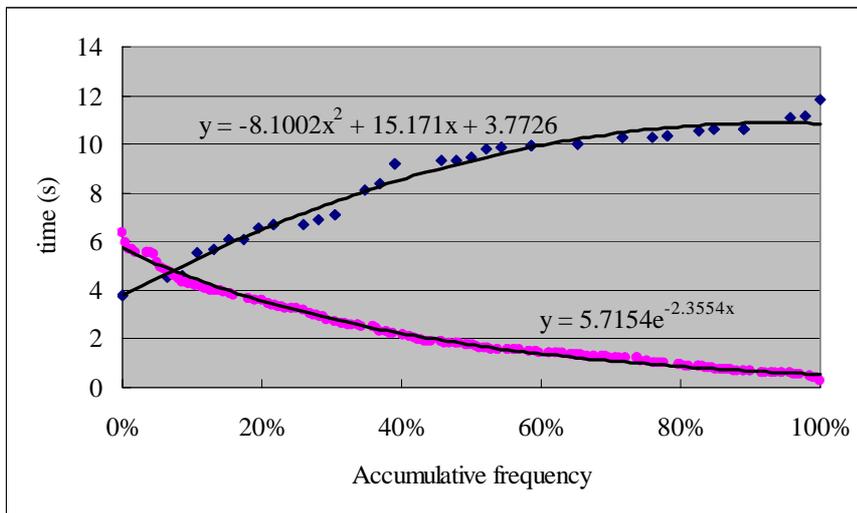

Figure 5   Scatter dots of accepted and refused gaps (Filtered data at crosswalk A).

Using the same method, the gaps data at crosswalk B are analyzed, which are showed in figure 6 and 7.
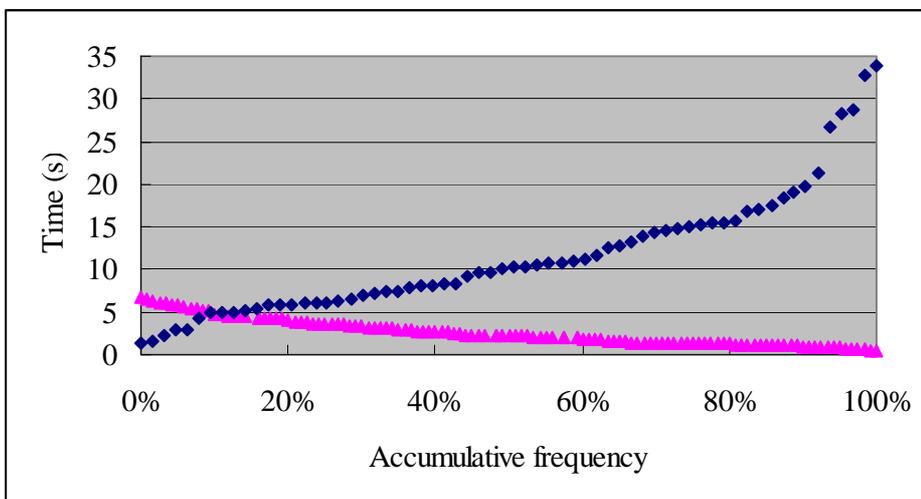

Figure 6   Scatter dots of pedestrian accepted and refused gaps (All data at crosswalk B).
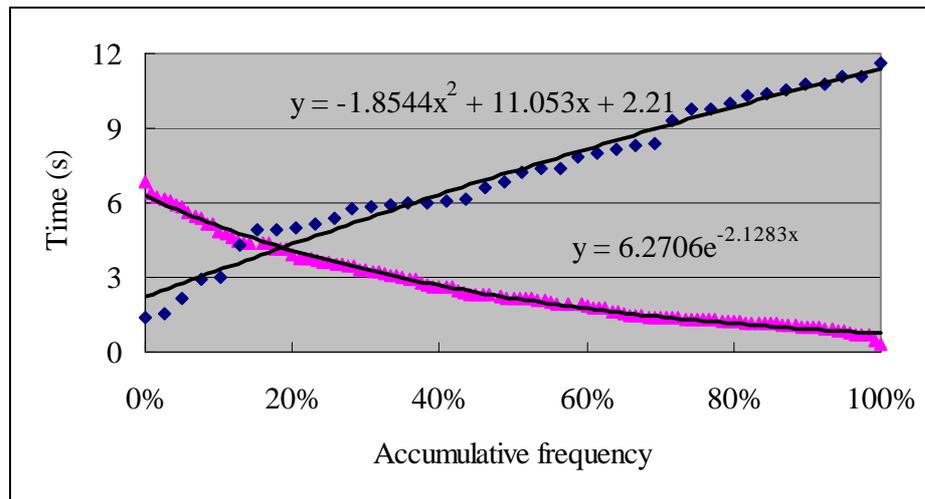
Figure 7 Scatter dots of accepted and refused gaps (Filtered data at crosswalk B).

The critical gap at crosswalk B should be 4.21s (with accumulative frequency is 18.7%), which is small than that at crosswalk A. The larger accumulative frequency reflects the more rate of ambiguous decision-making in pedestrians. The reason should result in the complex condition and competition of pedestrian and vehicle on the right of road.

That the more vehicle volume will generate less ht, in the similar speed. According to the observation, there are some vehicles more than 1/20 slow down for the crossing pedestrian in platoon, which forming by walking together or waiting in the same spot. It can be separated in two parts that the reason why drivers slow down or even brake for a full stop for pedestrian: one is active mode, another is passive mode. Some drivers yield when they saw there are pedestrian group who attempt to walk across, because they know the pedestrian in group are apt to take risk crossing. And some drivers want to keep their speed but they have to yield because "brave" pedestrian or pedestrian group did keep walking ahead instead of standing for a halt. The mode relate to the strength of occupied and behaviours to reach the desire.

There are more pedestrian cross street at B area. The chance of group generation increases and more pedestrian will walk together and less pedestrian walk singly. Pedestrian in larger group will not only encourage each other to stimulate the behavior, but also the upgrading visibility will influence the vehicle drivers. From the diagram it can tell out that the location of crossing of two trend curves are different from each other. At crosswalk B, the point is near 20% and it is less than 10% at crosswalk A. It also shows that the behaviours at crosswalk B are more varied than that at crosswalk A. That means in the same condition at the two crosswalks, there are more than 10% pedestrian will not so clear to make decision on the gaps. The behavior will more ambiguous thus it results in more complex walking environment. When the pedestrian is not so weak at the same condition, some of them will not resist on standing when vehicle coming. In the two participants of the game (competition of right of way) the characters and choices will vary. But the safety condition will decrease for the increasing probability.

ANALYSIS ON WALKING TACTICS

Pedestrian has his/her own manner when crossing road and the tactics are sorted into 4 types (6):

1) Walk through upright to roadside in crosswalk area directly in sufficient gaps;

2) Pedestrian cross road sideling with noncompliance (not upright to roadside and along with the direction of crosswalk);

3) Walk through road by lanes, using the gap of each lane instead of the road;

4) And at first start walk with uncertain judge on gap, retreat and waiting for sufficient gap, to finish walking in one of the three tactics mentioned above.

The tactic pedestrian used are influence by personal manner, vehicle traffic condition, and some factors in environment.

The least cost is one principle in walking. Some pedestrian walk through road towards his/her own destination for short cut instead of along the crosswalk, when the destination is not towards crosswalk directly.

There are 3 lanes in each direction in the survey spot and some pedestrian walk through by lane according to the vehicle occupy upstream. When they meet insufficient gaps, they will wait on lane line.

In observation, two tactics were added for detail description. They are:

5) Walk through upright to roadside but out of crosswalk area on road;

6) And running instead of walking.

Noncompliant pedestrian may cause many hidden trouble on crosswalk. In observation, about 1/5 to 1/4 of pedestrians in category 2 walk using tactic 3 in simultaneity.

Figure 8 shows the percentage of each tactics at north section of road at crosswalk A, with 356 samples.
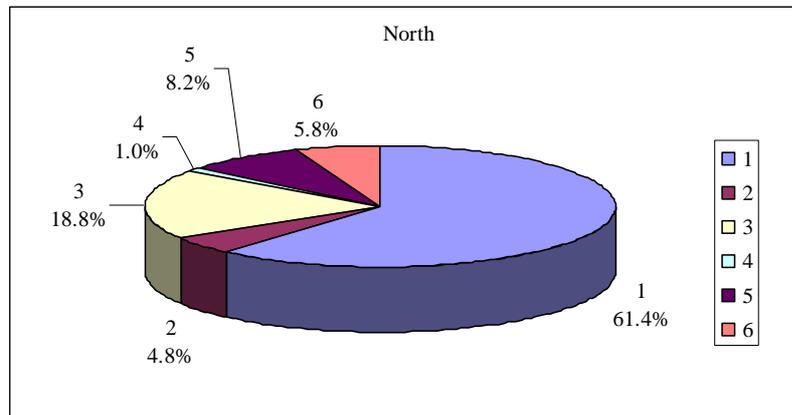

FIGURE 8 Pie chart of pedestrian tactics at crosswalk A.

At crosswalk B, pedestrian/bicycle riders cross more freely for they are not restricted with the facilities such barrier. And the area is not clearly channelized for vehicle, more like a little square service for different traffic entities in different directions. Thus the walking tactics are sorts by two types, which consist of three subtypes respectively. The 6 types of walking tactics are showed as follow.

1) Ride a bicycle/Running, cross road sideling;

2) Ride a bicycle/Running, upright to roadside and along with the direction of crosswalk;

3) Ride a bicycle/Running, in the zone of crosswalk;

4) Walking, cross road sideling;

5) Walking, upright to roadside and along with the direction of crosswalk; And

6) Walking, in the zone of crosswalk.

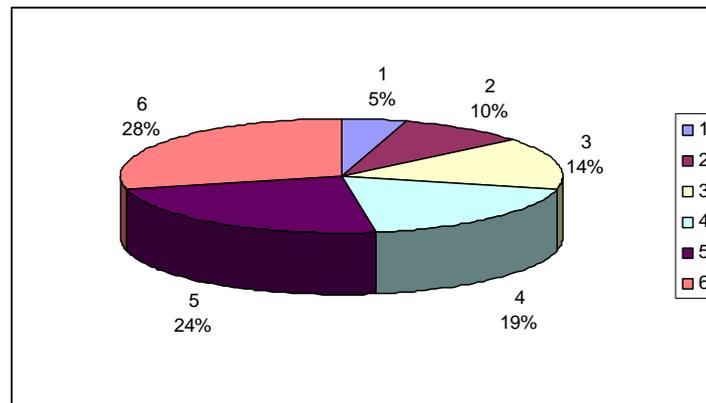Figure 9 shows the percentage of each tactics at east section of road at crosswalk B, with 400 samples.

FIGURE 9 Pie chart of pedestrian tactics at crosswalk B.

To compare the two tactics composition, it can be found that with rigid restriction and management, the rate of non-compliance will decrease, which is benefit for the VRUs safety. But the reason that pedestrian or bicycle riders with non-compliance result from improper facilities and management. And it also shows the lack on traffic rule instruction and education, which are the root of the incorrect manners and improper behaviours.

Another situation should be mentioned at crosswalk B area. Because the crosswalk link to two zone of campus, most of pedestrian are inner pedestrian traffic of university. To avoid conflict and smooth the vehicle flow and continuous pedestrian route, an overpass had been built for crossing pedestrian. But the road direction was not separated for vehicle entering and going out of campus, so the overpass is used only by few pedestrian. In contrast, in an hour, only 37 pedestrians have been counted on overpass.

For the safety and traffic order, strong management should be used, with convenience consideration for VRUs.

RELATIONSHIP BETWEEN GAPS AND WAITING

Pedestrian take a longer gap in crossing than vehicle, because they are vulnerable road user and easy to injury in conflict. Although pedestrian occupies absolute priority in crosswalk, they seldom walk in rushed even they arrive earlier.

Pedestrian keep waiting for accept gap. But when the waiting time is too long to forbear, the behavior and traffic characteristics of pedestrian may change. Some pedestrian will take a shorter gap after refusing several longer gaps. They run across in risk and the drivers have to slow down or change lane to keep safety space, which is disturb in traffic system.

In observation, at crosswalk few pedestrian took adventure and most pedestrian yield to vehicle. The condition that vehicle yield to pedestrian did not appear, which made pedestrian keep a long waiting time for acceptable gaps. And pedestrian will gather and walk across in platoon or crowd. In similar spots, the acceptable gap relies on physical condition and mental condition and waiting time.

The relationship between pedestrian behavior change and waiting time is very complex. In the paper, the relationship between condition if pedestrian with the action of waiting and acceptable gap was discussed in simplification, by explore analysis. Figure 10 is the box plots of acceptable gap of pedestrian with waiting or not at cross walk A. It shows that acceptable gap when after waiting is centralization in smaller range than that of without waiting, which can interpret as vehicle restrict pedestrian personal characters in walking. The waiting period is a preparation for walking across the street, so the average gaps is smaller than that without waiting.
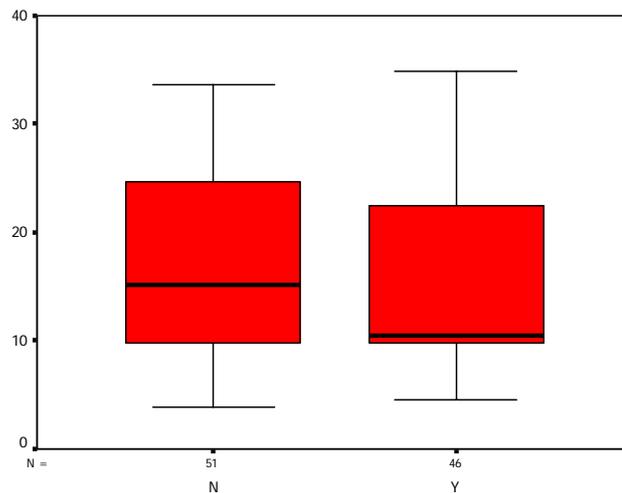
FIGURE 10 Box plots of acceptable gaps in condition of with waiting (Y) and without (N).

CONCLUSION AND RECOMMENDATION

This research attempts to enrich the database of pedestrian research, in the field of traffic characteristics and safety, by analyzing on speed, behaviors and critical gaps. The numerical values in this paper are useful for signalization. Walking speeds and decision-making behaviors are influenced by traffic condition nearly, so supposed condition should be considered at the crosswalk design. The safety condition of pedestrian will improved with the removing of ambiguity.

According to the result and comparison, there are some recommendations about this type of crosswalk:

➢ To install pedestrian signal to remove the conflict between vehicle and pedestrian, and the signal is advised using push-button.

➢ On each end of crosswalk, a supplemental plaque sign should be set up to guide pedestrian walk in crosswalk area. And

➢ The waiting zone for pedestrian standing should be considered in design, depending on number of assembled pedestrian results from acceptable gap of pedestrian when they cross street, the forecast vehicle volume and number of pedestrians in a minute.

The activities in observation should be taken in consider in traffic safety management. Education, enforcement, engineering, and many related works should be carried out in application to improve traffic condition. It is responsibility for both policy makers and technical staffs to improve pedestrian safety, convenience, and road traffic efficient. The related operations consist of the follows:

➢ To execute education and enforcement works continually to decrease pedestrian noncompliance when they across street.

➢ To propagandize driving in traffic calming campaign to advise drivers to slow down or stop to yield to pedestrian at crosswalk, the vulnerable road users. And

➢ To install guardrail in the middle of road to lead pedestrian using overpass for safety and order consideration.

The data of the crosswalks was extract from the videos recorded before the reconstruction of the conflict area. Fortunately, a set of signal had been installed at crosswalk A and at the west gate the road direction is separated by guardrail, crosswalk B being removed. The conflicts were eliminated and the effect will be analysis with Before/After method in different period after the measurements.

ACKNOWLEDGEMENT

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