Analysis of Relationship among Intersection Geometry, Users' Behavior and Traffic Safety Based on Before-and-After Survey Data

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Abstract: We quantified the changes in both utilization characteristics and traffic conflict risk at signalized intersections with improvement of geometry and developed the evaluation model for measuring traffic conflicts between left/right-turn vehicles and pedestrians in order to clarify the relationship among the size of intersection, users’ behaviors and traffic safety. Through the before-after analysis, it was found that the risky behaviors during inter-green period such as rushing into intersection for both drivers and pedestrians have decreased and the traffic conflict risk has also drastically reduced by the compactly-modified intersection. It was also revealed by the developed risk estimation model that the longer time the left/right-turn vehicle requires to pass at intersections, the higher conflict risk occurs. And it was confirmed that the traffic conflict risk may be reduced by the further improvement of intersection geometry through the sensitivity analysis.

Key Words: Conflict Risk, Traffic Safety, Intersection Geometry, Users’ Behavior

1. BACKGROUND

In Japan, intersections are normally designed to be as small as possible, as described in the several technical guidelines (e.g. JSTE(2002), (2006), etc.). Meanwhile, several intersections have been designed to be of a large size by setting the crosswalk a long distance away from the intersection or designing gently curved corners, taking into consideration the safety of pedestrians and allowing easy driving for vehicles turning right or left. Vehicles require a longer time to pass such large intersections; consequently, the inter-green period, which is the time between two green lights or the amber and red light period, is set to be longer. In such a situation, it is feared that commuters waiting for a green signal could try to avoid enduring the long waiting time and resort to risky behavior such as ignoring the red light or rushing into
intersection during the inter-green period. Moreover, vehicles turning at gently curved corners
could do so at a high speed; in such a situation, there is a high possibility that accidents or
collisions will occur.

In light of these issues, projects to improve the intersection geometry are being introduced. Under the
scope of these projects, the intersections are being downsized by moving the corner
cut, crosswalk, and stop line towards the center of the intersection. This is being done to
benefit the traffic at the intersections in the following two ways: the early detection of
crossing pedestrians by drivers of turning vehicles and a decrease in the speed of the vehicles
at these corners. Though this project has been in operation for a few years, only the change in
the number of traffic accidents or qualitative effects has been reported and the changes in
vehicle movements and pedestrians’ safety by introducing the countermeasure hasn’t been
quantitatively-analyzed from the microscopic viewpoint in detail. As for the existing related
researches, there are some studies for the purpose of examination of the impact of the
relationship between users’ behaviors and intersection geometry on traffic capacity of
signalized intersection (e.g. Kawai et al (2002)). On the other hand, there are limited number
of researches for the effect of the relationship between users’ behaviors and intersection
geometry on traffic safety at signalized intersection in detail, though Yukawa et al (2010)
developed the turning vehicles’ trajectories model at intersections or Suzuki et al (2010)
analyzed start-up behavior of the first entering vehicle considering interaction with the
clearing vehicle in order to forecast traffic safety.

In this study, the utilization characteristics such as approach speed, entering timing of
intersection, and the change in traffic conflict risk are quantified through before-after
analysis, and an evaluation model for measuring traffic conflicts between turning vehicles and
pedestrians is developed to clarify the relationship among the size of the intersection, drivers’
and pedestrians’ behaviors, and traffic safety.

2. OUTLINE OF OBSERVED SURVEY AND SITE DESCRIPTIONS

Before-and-after field surveys were conducted at one intersection in Nagoya city, Japan,
where the intersection geometry had been modified in 2007; one survey was conducted before
the improvement in the intersection geometry in 2004 (hereafter called “Before”) and the
other survey was conducted after the improvement in 2008 (hereafter called “After”). For this
study, data was collected using video cameras for both vehicle movement and pedestrian
behavior.

Figures 1 and 2 show the intersection geometry and the phasing plan at the intersection under
observation, and Table 1 shows the traffic situation at this site. In the figure, red region means
after situation, and the use of line “A”, “B”, “C”, “D” and “E” are to grasp the vehicle
behavior in a later chapter. And it is found that the cycle length of after situation is shorter
than that of before situation and the setting of several split are changes from the
representative phasing plan. From Table 1, it is evident that there are no significant changes in
the hourly traffic volume at the site.
Figure 1 Geometry of observed intersection

Figure 2 Representative phasing plan applied at the intersection under observation (Y: yellow time, AR: all red time)

Table 1 Hourly traffic volume for each approach at this site

<table>
<thead>
<tr>
<th>Direction</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right-turn</td>
<td>Through</td>
</tr>
<tr>
<td>North-Bound</td>
<td>42</td>
<td>398</td>
</tr>
<tr>
<td>South-Bound</td>
<td>91</td>
<td>571</td>
</tr>
<tr>
<td>West-Bound</td>
<td>254</td>
<td>808</td>
</tr>
<tr>
<td>East-Bound</td>
<td>98</td>
<td>703</td>
</tr>
</tbody>
</table>

[Unit: vehicle per hour]
3. ANALYSIS OF APPROACH TIMING AT INTERSECTIONS

3.1 Analysis of time required to pass stop-line for each movement

This section analyzes the changes in the rushing-in of the West-bound vehicles into the intersection during the inter-green periods by comparing the results of the before-and-after survey. Figure 3 presents the signal phases when the approaching vehicles pass the stop-line for each movement.

From the figure, it can be seen that the percentage of vehicles rushing into the intersection after the amber light has decreased for vehicles turning left and vehicles going straight. It is thought that the length of the stopping distance for the ex-post situation is longer than that for the ex-ante situation because of the improved geometry whereby the stop-lines have been moved forward by as much as 10 m towards the center of the intersection, as shown in Figure 1.

On the other hand, it can be seen that the number of the right turning vehicles, which have rushed into the intersection after the amber light increases. This was perhaps caused by the shortening of the exclusive right-turn phase from 8 s for the ex-ante situation to 6 s for the ex-post situation.

![Figure 3: Signal phases when the approaching vehicles pass the stop-line for each movement](image)

3.2 Aggregate analysis of pedestrians’ risky behavior

This section focuses on the pedestrians’ behavior at the North and the East sides of the intersection, which are related to the traffic conflicts with the left/right turning vehicles. Table 2 presents three items: the number of pedestrians who start crossing before the green light is on, the number of the remaining pedestrians on the crosswalk after the red light, and the number of pedestrians who start crossing after the green light flashes. Bicycle users who cross the crosswalk are treated as pedestrians in this study.
Table 2 Aggregate analysis of pedestrian behavior

<table>
<thead>
<tr>
<th>Item</th>
<th>East side crosswalk</th>
<th>North side crosswalk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>The number of pedestrians who start to cross before green light</td>
<td>5(0.02)</td>
<td>10(0.03)</td>
</tr>
<tr>
<td>The number of pedestrians who starts to cross after flashing green light</td>
<td>67(0.23)</td>
<td>20(0.06)</td>
</tr>
<tr>
<td>The number of remaining pedestrians on the crosswalk after starting the red light</td>
<td>33(0.11)</td>
<td>46(0.14)</td>
</tr>
<tr>
<td>Total number of pedestrian [person/hour]</td>
<td>296</td>
<td>320</td>
</tr>
</tbody>
</table>

(The ratio of each item to total number of pedestrian)

As can be seen from the table, the number of all events for the ex-post situation is smaller than that of the ex-ante situation for the North crosswalk. On the other hand, the decrease in the number of remaining pedestrians after the red light and the crossing pedestrians before the start of the green light, can’t be confirmed, though the number of pedestrians rushing into the intersection has decreased for the east crosswalk A possible explanation could be that the flashing time of the green light was set for a shorter duration and the red time before phase-6 was set for a longer duration, after the improvement was carried out.

4. ANALYSIS OF CHANGE IN SPEED CHARACTERISTICS

To grasp the potential risk of conflict at the intersection, the approach speed of vehicles turning right and the vehicles turning left was measured. Speed was calculated by using the passing time at each section and the stage length, as shown in Figure 1. In addition, the speed of the vehicles turning left was measured at sections A-B and B-C; on the other hand, the speed of the vehicles turning right was measured at sections A-D and D-E.

Moreover, the traffic was divided into two groups at the phase when the drivers had passed the stop line. This division is as follows: For left-turn movements, the vehicles that passed the stop line from phi-1 to phi-3 are defined as “Passed the intersection on a green light” and other vehicles that passed it from Y1 to AR2 are defined as “Rushing into intersection (Intergreen).” For the right-turn movements, the vehicles that passed the intersection from phi-1 to phi-4 are regarded as “Passed the intersection on a green light” and the other vehicles that passed it from Y2 to AR2 are also defined as “Rushing into intersection.”

Table 3 and Table 4 show the basic statistics for the speed characteristics of vehicles turning left and the vehicles turning right at the intersection in order to compare the results of the before-after situation.
Table 4 Basic statistics for speed characteristics of vehicles turning right

<table>
<thead>
<tr>
<th>Section A to D</th>
<th>Section D to F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green light</td>
</tr>
<tr>
<td>Before Average speed [km/h]</td>
<td>13.1</td>
</tr>
<tr>
<td>Standard deviation [km/h]</td>
<td>9.1</td>
</tr>
<tr>
<td>Sample size</td>
<td>401</td>
</tr>
<tr>
<td>t-statistics</td>
<td>3.2</td>
</tr>
<tr>
<td>Statistical significance</td>
<td>1%</td>
</tr>
</tbody>
</table>

Table 3 shows that there is a decrease in the velocity of the left-turn vehicles after the situation. According to the t-statistics, it is confirmed that there are statistically significant differences between the before-and-after situation for both the sections and the timings. This is because of the improved intersection geometry, where the corner curve has been sharpened and the stop line and crosswalk moved toward the center. This shows that the modification affects the early detection of crossing pedestrians and alerts the possibility of rear-end accident by shortening the storage length of these vehicles to the drivers of vehicles turning left.

As for the speed characteristics of vehicles turning right, as shown in Table 4, the speed of both the sections during the green light decreased; however, a different trend has been shown in the result during the “inter-green” period. This implies that relaxed drivers who pass during the green light tend to deal with the change in intersection geometry calmly, but drivers who enter the intersection at the inter-green period lack the emotional capacity to reduce their speed.

From the above analysis, it can be concluded that the damage caused by traffic accidents has reduced by the improvement in the intersection geometry, because in general, the speeds of the turning vehicles after the modification have drastically decreased.

5. ANALYSIS OF TRAFFIC CONFLICT RISK ASSOCIATED WITH REAR-END ACCIDENTS AT INTERSECTIONS

This chapter focuses on the risk of traffic conflict associated with rear-end accidents at intersections from the viewpoint of the proportion of traffic stopped near the stop line and the existing conflict risk index.

5.1 Analysis of proportion of traffic stopped near stop line during inter-green period

When an approaching vehicle with several vehicles following it at the inter-green period determines whether it can or cannot pass through the intersection near stop line, the judgment of the leading vehicle has great relevance on the rear-end collisions. This is because the vehicles following it may make a judgment error on whether the leading vehicle will stop at the stop line or not. Therefore the proportion of the vehicles that stopped was measured in this section.

Here, it is set the several sections in order to analyze the stopped position, as shown in Figure 4. For both the before-and-after surveys, the stop line was defined as $L_1$, the edge-line on the West side of the crosswalk as $L_2$, and the entrance line that connects the median with the
Southeast corner cut as L13, separately for the East side approach. Here, “i” means the survey period. Figure 5 presents the proportion of the stopped position over the defined three lines for each movement during their inter-green periods. In addition, it targets the traffic turning left and the traffic going straight through from Y1 to Phi4 and the vehicles turning right from Y2 to AR2.

As for the traffic turning right and that going straight through, the proportion of stopped vehicles over the stop line under the before situation was almost over 50% and that of the after situation was reduced to half of its previous value. On the other hand, by comparison of the before-and after situation, it shows that the value drastically dropped for the left-turn traffic. This is because drivers can easily stop before the stop line as the stop lines have been advanced toward the center of the intersection, especially the large displacement of the stop line for the left-turn traffic. Moreover, the proportions of both L12 and L13 were also reduced because the storage spaces become narrow. Thus, the results show that the moving of the stop line and crosswalk toward the center of the intersection is helpful for traffic control.

![Figure 4 Definition of stopping place for each movement during their inter-green periods](image)

![Figure 5 Proportion of stopped position over the three lines defined for each movement during their inter-green periods](image)
5.2 Evaluation of rear-end collision risk by PICUD index

In this study, the PICUD (Possibility Index for Collision with Urgent Deceleration) index was adopted to evaluate the rear-end collisions under the following situation. This index was proposed by Iida et al. (2001), and it is defined as the distance between the leading following vehicles when the former has rapidly decelerated and the latter has started to decelerate with a reaction delay time and stopped with urgent deceleration. PICUD is shown as equation 1. A negative value of the index implies that a crash has occurred.

\[
PICUD = \frac{V_1^2}{2a_i} - \left( V_2 \Delta t + \frac{V_2^2}{2a_2} \right) + s_0
\]  

(1)

where

\( V_1 \): Speed of the lead vehicle just when it starts to decelerate [m/s]
\( V_2 \): Speed of the follow vehicle just when the leader starts to decelerate [m/s]
\( s_0 \): Distance between the leader and the follower at the timing of urgent deceleration [m]
\( a_i \): Decelerate rate [m/s^2] (In this study, it assumes “5.6(0.6G)” [m/s^2])
\( \Delta t \): Reaction delay time [s] (In this study, it assumes “0.7”[s])

First, the traffic conflicts for the left-turning vehicles during green light were analyzed. Figure 6 shows the result of calculation of PICUD and cumulative distribution for each survey at the intersection. In addition, each PICUD data is used by extracting the minimum value when the vehicle has passed from the stop line to the crosswalk of the outflow channel. Table 5 shows the data which were used to calculate the average value of PICUD and the result of statistical test. T-statistics is to verify the difference in the average value of after situation and before situation for each variable. It can be seen that the proportion of negative PICUD value for the before situation is higher than that in the after situation. And from the table, it can also be seen that the average value of PICUD for after situation is larger than for the before situation, while the headway distance of after situation become shorter. However, statistical significance cannot be confirmed, it can be considered that the conflict risk between a left-turning vehicle and a left-turning vehicle under the following car situation have declined somewhat as a result of the improvement in the intersection geometry.

![Figure 6 PICUD distributions for left-turning traffic measured during green light](image)

| Table 5 Statistical properties of data which were used to calculate PICUD value for left-turning traffic measured during green light |
|---|---|---|---|---|
|                  | PICUD[m] | s_0[m] | \( V_1 \) [m/s] | \( V_2 \) [m/s] |
| **After** (N=96) | Average  | 1.03   | 4.54   | 3.17   | 4.14   |
|                  | SD       | 2.03   | 2.27   | 1.89   | 1.86   |
| **Before** (N=53)| Average  | 0.76   | 6.08   | 4.36   | 6.03   |
|                  | SD       | 2.71   | 3.49   | 2.81   | 2.49   |
| **t-statistics** |          | 0.67   | -3.22  | -3.04  | -5.20  |
Second, the traffic conflicts during the inter-green periods near each stop line were quantified. Figure 7 shows the results of left-turning and straight-through traffic and Figure 8 presents the result for right-turning traffic. Table 6 and Table 7 show the data which were used to calculate the average value of PICUD and the result of statistical test as well as Table 5. Here, the results of left-turning vehicles connect with straight-through traffic because of the lack of sample size.

Figure 7 shows that the proportion of the negative value for the after situation is higher than that in the before situation. And Table 6 also shows the average value of PICUD for these movements become smaller than for before situation. From the viewpoint of microscopic traffic situation, it can be thought that the amount of decrease in velocity of the two vehicles is small against the shortened headway distance between the vehicles however statistical significance cannot be confirmed. It is necessary to analyze this point in detail and is an issue for the future.

Figure 8 indicates that the before situation was more dangerous than the after situation for the right-turning traffic. And it can be found that the statistically-significant difference in the average value of PICUD between before and after situation is confirmed by the result of one-sided testing as shown in Table 7.
6. ANALYSIS OF POSSIBILITIES OF TRAFFIC CONFLICTS OCCURRING BETWEEN PEDESTRIANS AND TURNING VEHICLES BY CONFLICT INDEX

6.1 Aggregate analysis of traffic conflicts between pedestrians and turning vehicles by PET index

In this section, we discuss the possibilities of traffic conflicts occurring between pedestrians and vehicles by analyzing the results 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 an index defined as post encroachment time (PET), which was devised by Allen et al. (1978) to evaluate traffic conflicts. The smaller the PET value, the higher the risk.

In view of the time required for a left-turning vehicle to pass through the intersection, a PET value within 3 s was considered as a conflict event. As for traffic conflicts that occurred at the East-side crosswalk, Figure 9 shows the frequency distribution for ex-ante PET values, and Figure 10 presents the frequency distribution for the ex-post PET values for each period of time surveyed. In the Fig.9 and Fig.10, sample size (N) means the number of conflict event for one hour defined above.

![Figure 9: Conflicts between left-turn vehicles and pedestrians](image1)

![Figure 10: Conflicts between right-turn vehicles and pedestrians](image2)
By comparing these two figures, it can be seen that after improving the intersection geometry, the number of traffic conflicts within 3 s was about a quarter of those for the ex-ante situation for right-turning traffic. Moreover, it can be seen that the number of traffic conflicts for left-turning traffic is reduced from 69 to 59; even right-turning traffic and the risky traffic conflicts, such as those within 1 s, are decreased. This confirms that traffic safety for this site has shown some improvement. In addition, between 1.4 sec and 2.0 sec, there seems to be reversal values between before and after study from the two figures, we will conduct a detailed analysis for this point.

6.2 Development of PET estimation model

In order to explain the factors that influence the traffic conflicts between turning vehicles and pedestrians, a regression model was developed in this study. In the analysis, the PET value was regarded as a dependent variable, and independent variables such as road structures and traffic characteristics were used as explanatory variables. Table 8 shows the result of parameter estimation. In addition, one can adopt this result because of the statistical significance of the F-value obtained by the analysis of variance in spite of its low accuracy in terms of the R-squared value.

First, the parameter of the dummy variable pedestrian red light is negative; this implies that the PET value becomes small when pedestrians cannot cross the road before the signal turns red. Second, the parameter of the dummy variable of the conflict pattern (1) is positive and the PET value becomes large; it can be considered that right-turning vehicles tend to be conscious of the pedestrian approaching from their right side and thus maintain a low speed as they pass the intersections. Third, the parameter of the dummy variable of the conflict pattern (2) is negative; it was found that traffic conflicts between a left-turning vehicle and a pedestrian approaching from the right side of the vehicle is a risky situation. It can be assumed that a left-turning vehicle always takes special precaution to not collide with bicyclists or pedestrians and as a result, their cautiousness for the pedestrian coming from the right side was insufficient.

| Table 8 Result of parameter estimation for PET estimation model |
|---|---|---|---|
| Explanatory variables | Unstandardized Coefficients | t-statistics | p-value |
| Constant | 0.51 | 1.27 | 0.20 |
| Dummy variable of pedestrian red light  
(The case that pedestrian can't cross the road before their signals turn red :1, The others: 0 ) | -2.51 | -4.17 | 0.00 |
| Dummy variable of the conflict pattern (1)  
(The case that conflicts between a right-turn vehicle and pedestrian who comes from right side of the vehicle: 1, The others: 0) | 3.14 | 2.57 | 0.01 |
| Dummy variable of the conflict pattern (2)  
(The case that conflicts between a left-turn vehicle and pedestrian who comes from right side of the vehicle: 1, The others: 0) | -1.47 | -3.24 | 0.00 |
| Delay time for turning vehicle which is suffered by waiting pedestrian's crossing when they arrive at the intersection [s] | -0.14 | -3.94 | 0.00 |
| The time lag between the start of green light and the time of occurrence of each traffic conflict [s] | 0.17 | 7.79 | 0.00 |
Fourth, it was also found that the delay time for the turning vehicles that waited for the pedestrian to cross when they arrive at the intersection, bring about the negative effect of traffic conflict. It can be considered that the longer the time of the turning vehicle at intersections, the higher the risk of conflict. This could be because of the length of corner curve for left-turning traffic and the distance from the stop line to the crosswalk of outflow side for right-turning traffic. Finally, it is seen that the parameter of the time lag between the start of the green light and the time of occurrence of each traffic conflict is positive. This indicates that PET value is increased as time passes, in other words, when the conflict occurs immediately after the green light starts, the intensity of conflict risk is high.

7. QUANTIFICATION OF TRAFFIC RISK BETWEEN PEDESTRIANS AND VEHICLES BY USING RISK ESTIMATION MODEL

The magnitude of the incidents of risk can be generally quantified as “risk value,” which is defined as a product of frequency and intensity of each risk incident, as shown below (The Society for Risk Analysis: Japan Section (2006)).

\[ R = P \cdot I \]

where

- \( R \): risk value,
- \( P \): probability of risk occurrence,
- \( I \): intensity of a risk,
- \( l \): risk incident \((l=1, \ldots, n)\)

We treat the two traffic conflict patterns on a crosswalk as risk incidents: one is the conflict between left-turn vehicles and pedestrians and the other is the conflict between right-turn vehicles and pedestrians, as for the variables shown in this equation (2); \( P \) means the probability that the turning vehicles or pedestrians reach the conflict point and \( I \) is defined as the reciprocal of PET. In addition, the probability is defined as the proportion of the traffic volume at a given time to the hourly traffic volume for each subject. The risk value per second is expressed by equation (3), and the total risk for both the traffic patterns is defined as equation (4).

\[ R_i = \sum_{t=1}^{n} r_i(t) \]  

\[ r_i = \sum_{j=1}^{m} \left( \frac{\sum_{j=v}^{N_{j,veh}(t)} \times \sum_{j=p}^{N_{j,ped}(t)}}{N_{j,veh:all} \times N_{j,ped:all}} \times I_{con}(t) \right) \]

where

- \( R_i \): Total conflict risk at crosswalk “i”, \( r_i \): Conflict risk per second,
- \( N_{veh}(t) \): Number of vehicles at the time of “t”, \( N_{veh} \): Number of vehicles per hour
- \( N_{ped}(t) \): Number of pedestrians at the time of “t”, \( N_{ped} \): Number of pedestrian per hour,
- \( n \): Cycle length [s], \( m \): Number of cycle per hour, \( I_{con} \): Reciprocal of PET at the time of “t”

Temporal variations of these variables at the crosswalk on the East side of the intersection, which are used for calculating “\( r_i \)” shown in Figures 11 and 12.
From Figure 11, it was found that the probability of a pedestrian reaching the conflict point achieves a peak at just after Phi-6, and it has a declining trend with time. On the other hand, it can be seen that the probability of a right-turning vehicle reaching the conflict point indicates a certain value after Phi-6 starts and the probability of left-turning vehicles reaching the conflict point fluctuates according to the value of $P_{\text{ped}}$.

Furthermore, it was also found that the arrival time of both the pedestrians and the turning vehicles after a situation is earlier than that of the before situation by comparing Figures 11 with Figure 12. This is because of the increase in the all red time before the green time for pedestrians and the shortened corner cut for the turning vehicles.

Moreover, as for the maximum value of intensity of risk, it can be seen that the value for left turning vehicles is about 40 and that for right turning vehicles is about 20 by comparison between these two figures. This shows that the length of time for which the conflicts between pedestrians and turning vehicles may occur for the after situation is shorter than that of the time for the before situation.

Figure 13 shows the conflict risk per second for both the situations that are calculated by using the above variables, as shown in Figures 11 and 12. As for the results, it was found that the conflict risk for the before situation is high at just after Phi-6 and in the middle of Phi-6, while the value for the after situation is nearly “zero.”
In addition, the total risk, which is measured by the sum of the conflict risk per second, is shown in Figure 14. From the figure, it can be seen that the total risk for the after situation is 0.01 while that for the before situation is 0.28, and the risk values for both the conflict patterns drop significantly. This reveals that the safety of this intersection is drastically improved by the counter measure that is downsizing the size of the intersection.

8. SENSITIVITY ANALYSIS OF DEVELOPED RISK ESTIMATION MODEL

In this section, we carry out sensitivity analysis by using conflict risk estimation model, as discussed in the preceding chapter. We focus on the variable “delay time for a turning vehicle that has waited at the pedestrian's crossing when they arrive at the intersection” as the explanatory variable. This valuable is affected by the change in the intersection geometry. Here, it has been assumed that the arrival patterns of the pedestrians and the turning vehicles is the same as the results of Figures 11 and 12 and estimates the total risk value when it varies the delay time for the turning vehicle, which has waited at the pedestrian's crossing when they arrive at the intersection, from 0 to 6 s on the 0.1 s time scale. Figure 15 shows the estimated R value and the relation between the delay time and R value.

The R value has been found to be stable when the delay time is under 4 s; however, when the delay time is over 4 s, the value fluctuates greatly. Meanwhile, it was confirmed that the average delay time is 5.6 s from the observed survey. The R value for the delay time indicates “0.91,” as estimated by the relational equation, shown in Figure 15. If we shorten the delay time from 5.6 to 4.0 s by changing the intersection geometry such as moving the stop line forward and shortening the length of the...
corner cut, the R value drops from 0.91 to 0.39 and the safety of this intersection improves. In summary, it is seen that the conflict risk may be reduced by a further improvement of intersection geometry through the sensitivity analysis.

\[
y = 0.1136e^{0.0371x}
\]

\[
R^2 = 0.7948
\]

![Figure15 Result of sensitivity analysis](image)

9. CONCLUSIONS

In this study, we quantified the changes in both utilization characteristics at intersections and traffic conflict risk through before-after analyses and developed the evaluation model for measuring traffic conflicts between turning vehicles and pedestrians in order to clarify the relationship among the size of intersection, drivers’ and pedestrians’ behaviors and traffic safety. The conclusions of this paper can be summarized as follows.

It became clear that the risky behaviors for both vehicle behaviors and pedestrians’ behaviors at inter-green periods were decreased by comparison of the before-and-after survey data. And it was also found that the entering speed of left/right-turn vehicles for the after situation was lower than that in the before situation. That is, the geometry improvements which are moving the corner cut, crosswalk and stop line inward side of the intersection has a positive effect for traffic safety.

It was revealed that the proportion of stopped vehicles over the stop line has dropped by the improvement of intersection geometry. In addition, it was found that the possibilities of rear-end accidents for right-turn vehicles during green time near at compactly-improved intersections has reduced from the viewpoints of PICUD index while the improvement effects for the conflict risk at inter-green periods were unverified by this study.

It was shown that both frequency and degree of traffic conflicts between pedestrians and left/right-turn vehicles after the improvement of geometry has decreased. Moreover, as for the effect factors of traffic conflicts at intersections, it was revealed that the remaining pedestrian on crosswalk after red light starts, the case that conflicts between left-turn traffic and pedestrian who comes from right side for the vehicle and delay time for turning vehicle which is suffered by waiting pedestrian’s crossing when they arrive at the intersection increase the
degree of conflict risk. Meanwhile the case that conflicts between right-turn traffic and pedestrian who comes from the right side for the vehicle and the time lag between the start of green light and the time of occurrence of each traffic conflict reduce the degree of conflict risk.

It can be seen that the conflict risk for the after situation has drastically reduced by the countermeasure which was compact-modified the intersection geometry and the risk may be reduced by the further improvement of intersection geometry through the model analysis.

As future works, we try to improve the accuracy of risk estimation model by increasing the number of surveyed intersection. In addition, we also analyze the relationship between the users’ arrival patterns and the parameter of traffic signal control in order to minimize the conflict risk at the compactly-improved intersections.

REFERENCES