ANALYSIS ON DRIVER'S AND PEDESTRIAN'S PERCEPTION FOR THE EVALUATION OF CYCLE LENGTH AT UNDER-SATURATED SIGNALIZED INTERSECTIONS

Koji Suzuki[a], Hideki Nakamura[b], Satoshi Yamaguchi[b]
[a]Nagoya Institute of Technology
Gokiso-cho, Showa-ku, Nagoya, JAPAN, 466-8555, Tel+Fax: +81-52-735-7962,
[b]Nagoya University, Furo-cho, Chikusa-ku, Nagoya, JAPAN, 464-8603
Phone: +81-52-789-2771; +81-52-789-3828
suzuki@ace.nitech.ac.jp; nakamura@genv.nagoya-u.ac.jp; syama@genv.nagoya-u.ac.jp

Abstract

The aim of this study is to propose a framework for evaluating cycle lengths based on user's perceptions and behaviors at under-saturated signalized intersections by following risk management methodology. Firstly, analyzing both frequency of risk and intensity of risk at inter-green periods, it is made clear that risky behaviors for through/left-turn movements are affected by delay, and for right-turn movements is influenced of traffic conflicts. Secondly, risky behaviors at inter-green periods are expressed by a behavior modeling technique in order to weight among the risk incidents. These models are explained by delay and various traffic conflicts, which are influenced by cycle lengths. The estimated parameters of these models quantitatively indicate that longer cycle lengths induce more risky behaviors at inter-green periods. Finally, via a sensitivity analysis, the impact of cycle lengths and intersection size on risk taking behaviors is demonstrated.

Keywords: User's perception; Risky behavior; Cycle length; Signalized intersection
Topic Area: C2 Safety Analysis and Policy

1. Introduction

When traffic control or management is implemented, it is important to demonstrate traffic flow conditions in a concrete and easily understandable manner as an index of "Quality of Service (QOS)". At signalized intersections, control delay has been commonly adopted as a performance measure; however, it is not guaranteed to reflect users' perceptions appropriately.

Presently, cycle lengths of traffic signals in Japan are generally longer than in other developed countries. They are set rather long even in off-peak hours, in order to secure more than enough green time for pedestrians. The long cycle lengths not only impose unnecessary delay upon users, but also often cause risky behaviors which may induce traffic accidents as a result. Not all of the users decelerate or stop safely in order to avoid traffic conflicts, but some are likely to ignore traffic signals since they hate extra delay. Thus, traffic signals, which must be a facility for safety, may often induce risky situations and excessive delay under inappropriate parameter settings. At signalized intersections, various "risk incidents" can occur, and users behave the risk avoidance or the risk taking, after evaluating his/her situation under a traffic condition. Thus, the relationship between risky behavior and decision-making process, which affected by operating conditions, should be carefully investigated. Cycle lengths must be evaluated also from the aspect of user's perception.

The objective of this study is to propose a framework for evaluating cycle length based on user's perceptions and behaviors at under-saturated signalized intersections, applying risk management methodology. User's risky behaviors at inter-green periods are expressed by a behavior modeling technique. Traffic conflict and delay are focused on as the risk incidents at signalized intersections in this study.

2. Framework of cycle length evaluation applying the risk management methodology

2.1. Definition of risk

The magnitude of risk incidents can be generally quantified as "risk value", which is defined as a product of frequency and intensity of each risk incident.

$$\boldsymbol{R}_l = \boldsymbol{P}_l \cdot \boldsymbol{I}_l \qquad (1)$$

where
R: risk value, *P*: probability of risk occurrence, *I*: intensity of a risk,
l: risk incident (*l*=1, 2,…, *n*)

This study covers two risk incidents, namely conflict risk and delay risk associated with parameter setting of traffic signal control and geometric conditions. The frequency and intensity of risk incidents are strongly dependent on traffic conditions. Each risk value is calculated by equation (1), and "total risk value" is expressed by a weighted sum of these risk values as the equation below.

$$\boldsymbol{R}_i = \alpha \cdot \boldsymbol{P}_{deli} \boldsymbol{I}_{deli} + \beta \cdot \boldsymbol{P}_{coni} \boldsymbol{I}_{coni} \qquad (2)$$

where
i: road user (driver, pedestrian, and cyclist), *con*: conflict, *del*: delay, α, β: parameter

In equation (2), *P* and *I* can be directly measured, while *R* cannot. Parameters α and β are estimated by using a behavior modeling technique, which is explained in Chapter 3. Thus, total risk value *R* can be calculated.

2.2. Risk management methodology

The risk management methodology consists of four steps; i) risk perception, ii) risk analysis, iii) risk evaluation and iv) risk control, check and feedback. Following this general concept, a framework of risk management procedure for the evaluation of cycle lengths at signalized intersections is assumed, as illustrated in Figure 1.

Firstly, i) risk incidents at a signalized intersection that are induced by inadequate cycle lengths are specified. Secondly, ii) the relationship between user's perception, judgment, behavior and risk incidents is analyzed. The risk value for each user is measured, through a field survey. As a result, the frequency of risk occurrence, the risk intensity and weights among risk incidents are estimated. Then, iii) the current cycle lengths are evaluated. For the evaluation, risk values of various users are considered by weighting them according to a share of those users at a intersection. Finally, iv) cycle lengths are reexamined and optimized considering loss times due to the number of cycles per hour and a minimum crossing time for pedestrians, as well as the estimated risk value.

Among these steps for the risk management procedure, ii) risk analysis part is mainly discussed in this paper.

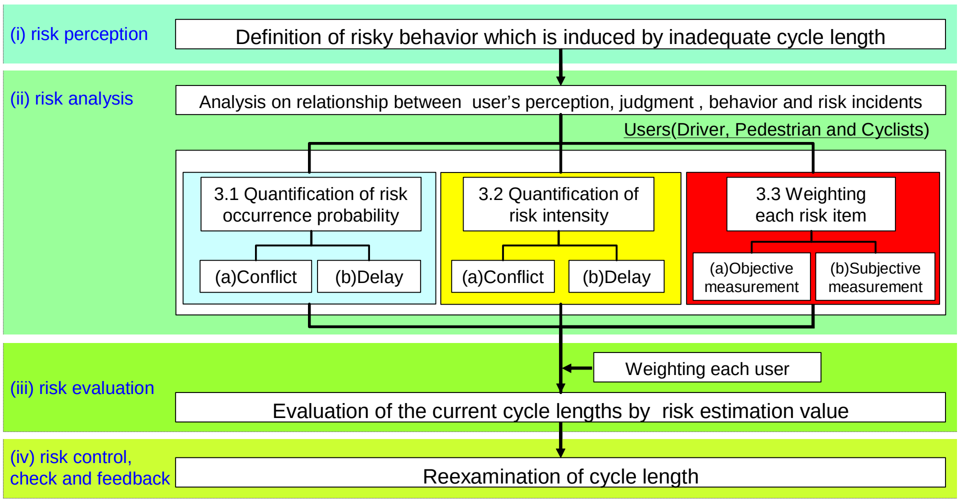


Figure 1 Risk management procedure for this study

3. Concept of risk analysis at signalized intersections

3.1. Quantification of probability of risk occurrence

(a) Traffic conflict

The traffic conflict at signalized intersections is one of the crucial risk incidents, and three major combinations of users are considered in this study: pedestrian versus vehicle, vehicle versus vehicle and bicycle versus vehicle. Details of conflict pattern are shown in Figure 2 and Figure 3.

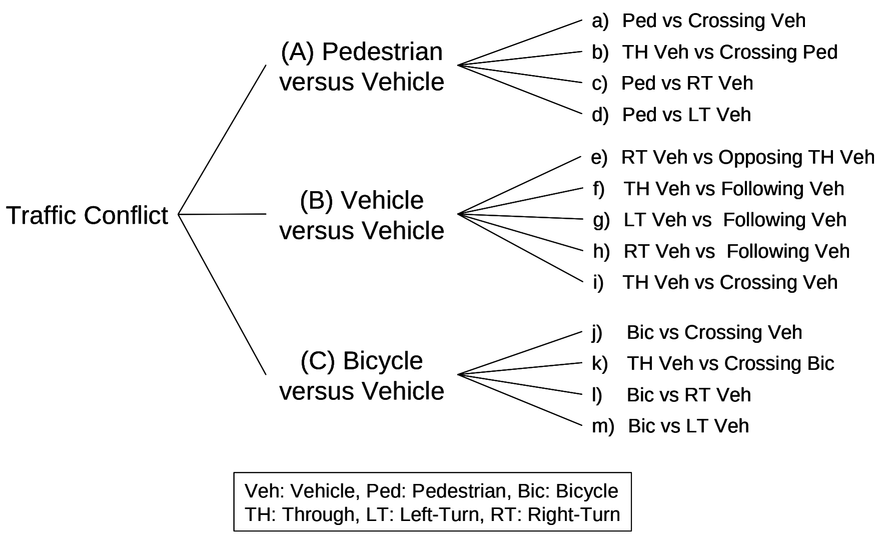
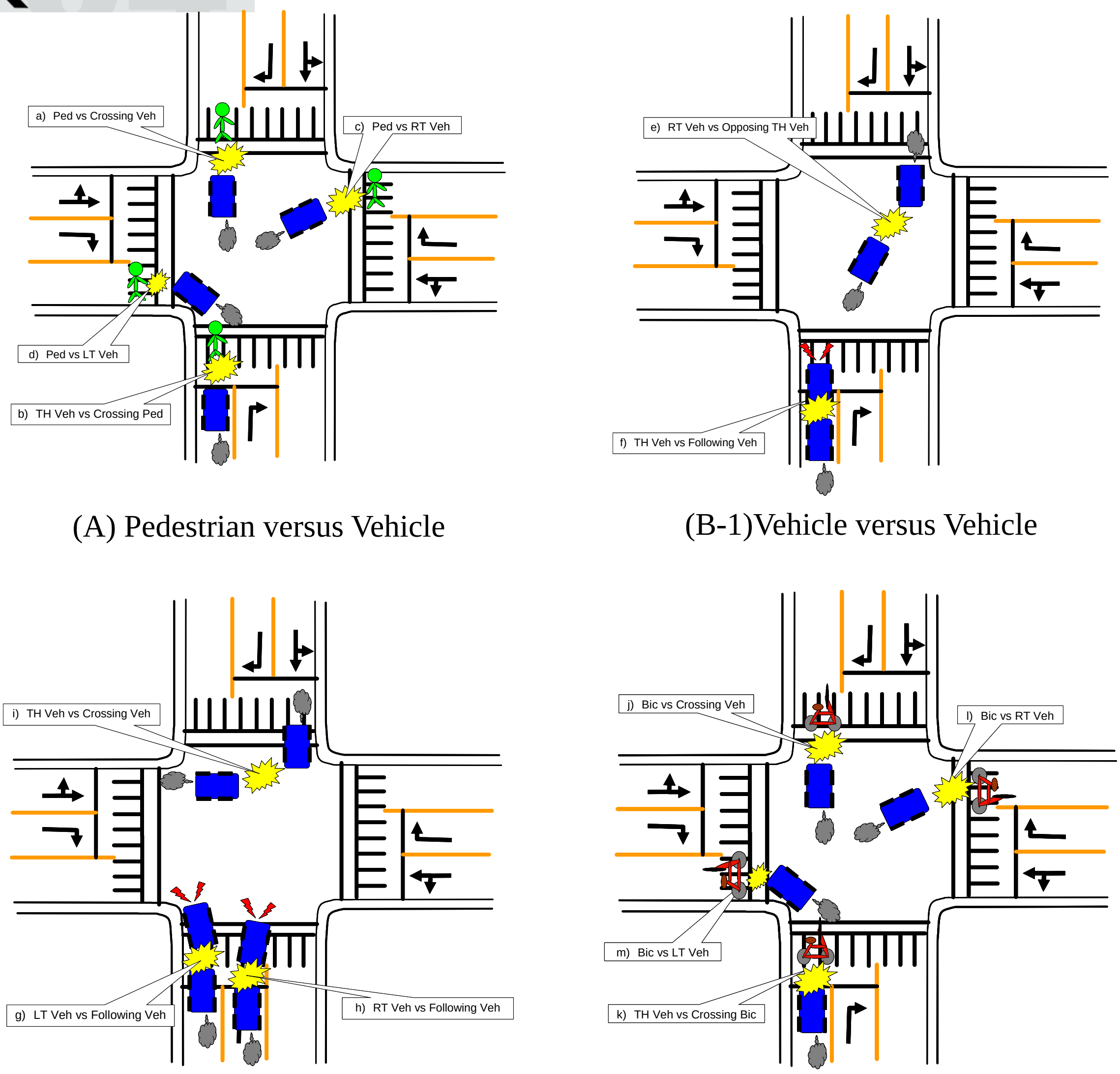


Figure 2 Major conflict patterns to be investigated



(A) Pedestrian versus Vehicle (B-1)Vehicle versus Vehicle

(B-2)Vehicle versus Vehicle (C)Bicycle versus Vehicle

Figure 3 Typical conflict patterns

These conflicts are likely to occur by such risk-taking behaviors as: hurry start (HS), violation of priority; rush into intersection (RI) at switching light, and ignoring traffic signals, etc. These behaviors at inter-green periods are particularly our concerns, since they have potentials to lead severe accidents due to higher approach speed of vehicles rushing into the intersection at these periods. Thus, frequency of traffic conflicts is measured by observing user's behaviors at inter-green periods in this study.

(b) Delay

In this paper, the major concern is risky behaviors by users arriving at a stop line during inter-green periods, and delays to be analyzed are for these users only. The probability of delay occurrence is defined as the stopping rate of these vehicles.

3.2. Quantification of risk intensity

(a) Traffic conflict

Some earlier researchers have proposed several indices as measures for representing intensity of conflict. Hayward (1972) proposed a TTC (time to collision) index, and PET

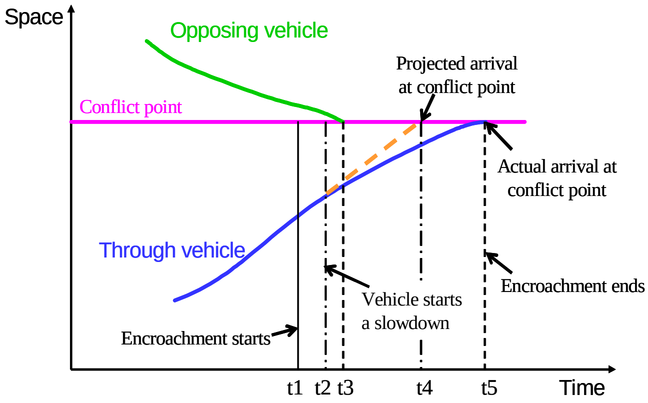


Figure 4 Definition of conflict indices

(post-encroachment time) was proposed by Allen *et. al*(1978). The latter index is adopted for expressing the conflicts with opposing vehicle and crossing vehicle in this study, though both of them are often adopted as indices for traffic conflict analyses.

The concept of PET is shown in a time space diagram of Figure 4 (Gettman, Head, 2003). PET is defined as t5-t3, which is the time lag between two conflicting vehicles reach the same point.

In this study, conflicts with a leader or a follower are explained by the reciprocal of headway, although TTC (time to collision) is desirable for this purpose. The resolution of the video images was not high enough to observe accurate individual speeds from them, which are necessary for TTC calculations.

(b) Delay

The intensity of delay is the delay value at a signalized intersection for each user who stops due to a red light.

3.3. Determination of the weights among risk values

Two approaches can be considered to determine the weights between the risk values. One is (a) objective measurement based on behavior observation and the other is (b) subjective measurement based on questionnaire survey. The former is adopted in this study. The weights between the risk values are calibrated by using behavior modeling technique. Judgments of whether a user takes such a risky behavior or not, as ignoring traffic signals, can be explained by disaggregate binary logit model. The utility function has variables on the risk values stated above.

$$P_{passi} = \frac{exp[\,u_{passi}\,]}{exp[\,u_{passi}\,] + exp[\,u_{stopi}\,]} \qquad (3)$$

$$u_{pass\,i} = \alpha' \cdot X_{deli} + \beta' \cdot X_{coni} + \varepsilon \qquad (4)$$

where:

P_{pass}: probability of passing intersection, u: utility of passage, α', β', γ': parameter, X_{deli}: delay risk, X_{coni}: conflict risk. These parameters α', β' can be regarded as the same parameters of equation (2).

4. Field survey for collecting risky behavior data

The frequency and intensity of each risk incident are measured through a field observation via video cameras. Data on pedestrian behaviors and vehicle movements are observed at several signalized intersections with different cycle lengths and geometric conditions in Nagoya City, Japan. The observation periods were 6:00-10:00am (intersections A, B and C) and 1:00-5:00pm (intersections B, D and E). Major features of the intersections are summarized in Table 1. All of these intersections, except for intersection A (three-phase), are operated by typical four-phase control for four-leg intersections. The right of way for pedestrians and cyclists is simultaneously given by pedestrian green lights at all of these intersections.

Typical Phase Plan at an inter-green period is shown in Figure 6 and detailed timings of inter-green periods are summarized in Table 2.

Table 1 Description of the intersections for investigation

Intersection	Cycle length [sec]	Total number of approach lanes (right-turn lane) EB/WB	Total number of approach lanes (right-turn lane) NB/SB	Phase plan	Size of intersection (L_{EW} x L_{NS}) [m x m]	Setback of stop line (S***) [m]
A (Jiyugaoka)	91	2(1)	2(1)	(TH+LT+PRT* / ERT** / TH+LT+PRT*)	27.7 x 29.8	14.1
B(Yotsuya)	130	3(1)	3(1)	(TH+LT+PRT*/ ERT**/ TH+LT+PRT*/ ERT)	55.5 x 57.8	16.6
C (Tashiro)	150	3(1)	3(1)		48.5 x 35.9	14.8
D (Imaike)	140	4(1)	4(1)		65.8 x 65.3	28.6
E (Gokiso)	140	3(1)	4(1)		56.3 x 53.4	21.8

*TH: through, LT: left-turn, PRT: permitted right-turn **ERT: exclusive right-turn

***S: values of setback of stop line for the analyzed direction of traffic

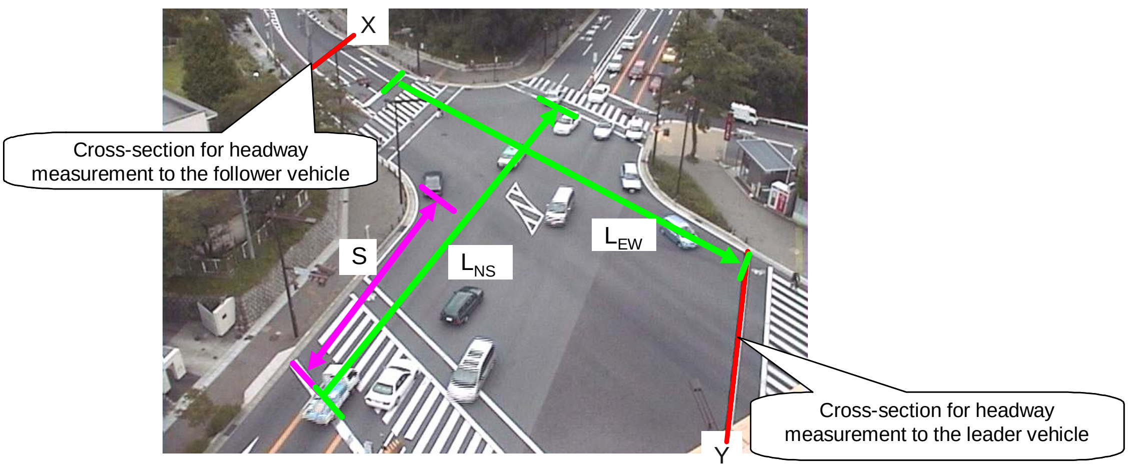
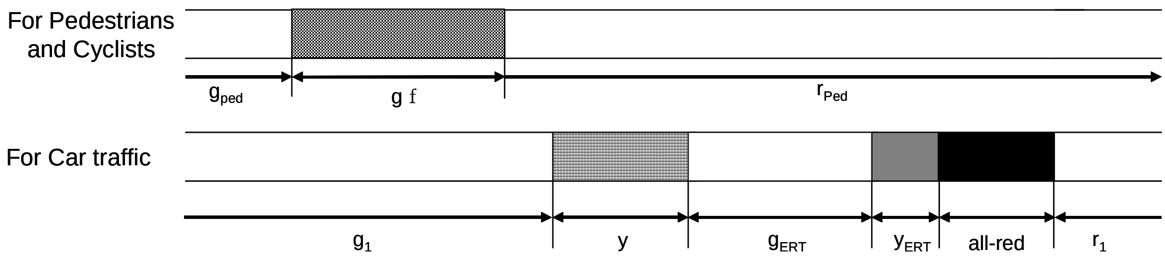


Figure 5 Example of observed intersection (intersection B)



g_{ped}: green period for pedestrians and cyclists, g_f: flashing green, r_{ped}: red period for pedestrians and cyclists, g_{ERT}: exclusive right-turn phase (ERT), y_{ERT}: yellow for ERT

Figure 6 Typical phase plan at an inter-green period

Table 2 Detailed timing of inter-green periods

Intersection	gf [sec]	y [sec]	g_{ERT} [sec]	y_{ERT} [sec]	all-red [sec]
A	6	3	7	2	3
B	8	4	8	2	5
C	7	3	11	-	4
D	8	4	10	-	5
E	9	4	10	-	5

5. Analysis on risky behaviors at inter-green periods via video image

5.1. Relationship between rate of risky behavior and risk intensity at inter-green periods for drivers

The cycle length can affect the frequency of such risk-taking behaviors as RI at inter-green periods. Here, the difference in risk behavior among TH+LT/RT movements is analyzed. The risky behaviors for TH+LT movements at yellow periods are analyzed for all of the observed intersections with a variety of geometric conditions, by selecting a time period with similar traffic flow conditions.

TH+LT vehicles that passed stop lines after the second half of the yellow phase are regarded as risk-taking vehicles and counted. The rate of RI (RRI) is defined as the value of the number of RI vehicles (NRIV) divided by the number of arriving vehicles (NAV) for 5 seconds before turning into red light. NRIV and NAV are summed up during the observation periods. Drivers' behaviors of these periods are compared with all intersections. The observed values for yellow periods are shown in Table 3.

Table 3 RRI after the second half of yellow phase for TH+LT movements

Intersection	RRI	Delay [sec/veh]	Average* PET[sec]	NRIV[veh]	NAV[veh]
A	0.11	48	1.43	6	53
B	0.22	77	1.70	8	36
C	0.19	81	1.59	7	36
D	0.31	88	1.99	44	142
E	0.26	97	1.78	22	86

* Averaged by the number of vehicles arrived during the second half of yellow phase.

A tendency of TH+LT movements is found that the larger the delay, the higher the value of RRI at the second half of yellow periods. This suggests that the delay caused by longer cycle length is one of the major causes of risk occurrence. The PET value with opposing vehicle at intersection A is the lowest of the five intersections. This is because of the size of the intersection, which is smaller than those of other intersection (see Table 1).

Table 4 shows the result for RT movements. The RRI after ERT phase of intersection C is higher than at any other intersections. This value is twice as high as that of intersection D, although delay does not differ. This result is considered due to their different surveyed time periods. It is easily imagined that the impact of one second during morning peak hours might be more significant for users than in the daytime.

On the other hand, the average PET value of intersection A is extremely high. This is because traffic volume of crossing direction was low, and this results in higher RRI irrespective of its smaller delay.

Table 4 RRI after ERT phase for RT movement

Intersection (survey period)	RRI	Delay [sec/veh]	Average PET[sec]	NRIV[veh]	NAV[veh]
A (am)	0.10	83	10.8	3	30
B (am)	0.09	109	4.90	1	11
C (am)	0.26	139	4.19	9	35
D (pm)	0.13	130	4.62	2	16
E (pm)	0.04	128	4.24	1	25

5.2. Rate of risky behavior at inter-green periods for pedestrians and cyclists

For pedestrians and cyclists, there are mainly two types of risk-taking behavior, the HS and RI after the flashing green. Here, the latter is analyzed by using survey data during each observation period.

Pedestrians and cyclists that start to cross after the flashing green are regarded as risk-taking behaviors and counted. The RRI after flashing green is defined as the number of RI behaviors divided by the number of arriving persons (NAP) during the period. The result for each user is shown in Table 5.

Table 5 RRI after green starts flashing for pedestrians and cyclists

Intersection (survey period)	Crossing road width [m]	Pedestrians				Cyclists			
		RRI		NAP		RRI		NAP	
		gf	r_{ped}	gf	r_{ped}	gf	r_{ped}	gf	r_{ped}
C (am)	17.7	0.75	0	4	0	1.00	1.00	12	5
E (pm)	25.7	0.38	0	13	6	0.97	0.86	38	14

*r_{ped} : $r_{pedestrian\ and\ cyclist}$

Both pedestrians and cyclists at intersection C are likely to rush into intersection after green starts flashing, compared with those of intersection E. This is because the crossing road width influences on risk-taking behaviors. The result of RRI reflects their different crossing speeds of different type of users (pedestrians / cyclists). Pedestrians mind turning into red on the way and are reluctant to cross, while cyclists enter with being confident to be able to cross before changing into red.

6. Parameter estimation of risk behavior model

6.1. Risk behavior model for driver at inter-green periods

Risky behaviors at inter-green periods are differently motivated by TH+LT/RT movement, as shown in the previous chapter. The probability of the judgments whether taking risky behaviors or not at inter-green periods can be explained by disaggregate binary logit model for these two movements.

The utility function of this model consists of explanatory variables that represent risk incidents such as conflicts and delay. These risk incidents are quantified in terms of driver's perception, and also influenced by cycle lengths.

$$\boldsymbol{u}_{pass_k} = \alpha' \cdot \boldsymbol{X}_{del} + \beta' \cdot \boldsymbol{X}_{confront} + \gamma' \cdot \boldsymbol{X}_{conrear} + \delta' \cdot \boldsymbol{X}_{conopp/cro} + \varepsilon' \qquad (5)$$

where

$\boldsymbol{u}_{pass}$: utility function of passing the intersection at inter-green periods
$\boldsymbol{k}$: turning movements (TH+LT / RT)
$\boldsymbol{X}_{dei}$: : delay [sec]
$\boldsymbol{X}_{confront}$: intensity of conflict with the front vehicle (leader) [sec^{-1}],
$\boldsymbol{X}_{conrear}$: : intensity of conflict with the rear vehicle (follower) [sec^{-1}],
$\boldsymbol{X}_{conopp/cro}$: : intensity of conflict with the opposing / crossing vehicle [sec],

α', β', γ', δ', ε' : parameters

Conflicts with a leader or follower can be explained by the reciprocal of headway, while PET expresses the conflict with the confronting vehicle. The result of parameter estimation for each movement is summarized in Table 6.

From the result of both movements, it is found that two conflict indices PET and $(\text{headway with leader})^{-1}$ have significant effects on risky behavior. Both estimated parameters are positive and rational. The former means, if the PET value is high, it becomes easier to pass without being disturbed by the conflicts with the opposing right-turn vehicle. The latter means, if a vehicle has a leader, it is more likely to choose the risky behavior, following his/her leader's behavior.

Table 6 Result of parameter estimation

Explanatory variables		Parameters (t-value)	
		a) TH+LT	b) RT
Stop	Delay[sec]	-3.33×10^{-2} (-4.03)	-
	$(\text{Headway to follower})^{-1}$[1/sec]	-1.90 (-2.94)	-
	Constant	5.60 (6.22)	3.77 (4.08)
Pass	PET*[sec]	1.32 (6.67)	0.558 (4.90)
	$(\text{Headway to leader})^{-1}$ [1/sec]	1.67 (2.91)	4.73 (3.79)
Number of samples		323	125
Likelihood ratio		0.290	0.372
Hit ratio[%]		78.3	80.8

* PET is expressed by conflicts with opposing right-turn vehicle for a) LT+TH and with crossing vehicle for b) RT.

The delay is statistically significant for LT+TH movements. The sign of the delay parameter is negative and rational. However, delay is not significant for RT movements. It can be considered that right-turners are more conscious of conflicts with other vehicles than delay, since the ERT phase is a limited chance that they have the right-of-way.

As for LT+TH movements, the parameter comparison of (headway to follower)$^{-1}$ with (headway to leader)$^{-1}$ indicates that the impact of a follower vehicle is about 14% greater than a leader. This means general drivers tend to care more about the collision risk from rear. Furthermore, from the parameter comparison of delay with PET suggests that the one second of the PET is equivalent to about 40 seconds of delay.

6.2. Risk behavior model for pedestrians and cyclists at inter-green periods

For pedestrians and cyclists, the probability of the judgment, whether taking risky behaviors or not after green starts flashing, can be explained by disaggregate logit model as well as the driver's model.

The utility function of this model consists of such explanatory variables as the conflict with left-turn vehicle and delay.

$$\boldsymbol{u}_{pass_i} = \alpha' \cdot \boldsymbol{X}_{conltv} + \beta' \cdot \boldsymbol{X}_{del} + \varepsilon' \qquad (6)$$

where

$\boldsymbol{u}_{pass}$: utility of passing intersection after green starts flashing
$\boldsymbol{i}$: road users (pedestrian / cyclist)
$\boldsymbol{X}_{conltv}$: intensity of conflict with left-turn vehicle
$\boldsymbol{X}_{del}$: delay for pedestrian and cyclist
$\alpha', \beta', \varepsilon'$: parameters

The result of the parameter estimation is shown in Table 7. The likelihood ratios of both models are high enough, although few samples were available and several variables are not statistically significant. The parameter of delay is negative and rational.

However, the parameter of PET for cyclists is not statistically significant. This suggests that cyclists may behave based on the different criteria from other users and further investigation is required.

6.3. Sensitivity analysis of risk behavior models

As shown in the previous sections, risk-taking behaviors for drivers and pedestrians are quantitatively explained by delay and conflict. Here, sensitivity of these indices to the

Table 7 Result of parameter estimation

Explanatory variables		Parameters (t-value)	
		Pedestrian	Cyclist
Stop	Delay[sec]	-0.236(-3.21)	-0.146(-1.64)
	Constant	22.2 (3.12)	7.99(1.13)
Pass	PET*[sec]	0.489 (0.82)	-0.703 (-1.45)
Likelihood ratio		0.676	0.784
Hit ratio[%]		92.9	87.8
Number of samples		40	62

* PET is expressed by conflicts with left turn vehicle

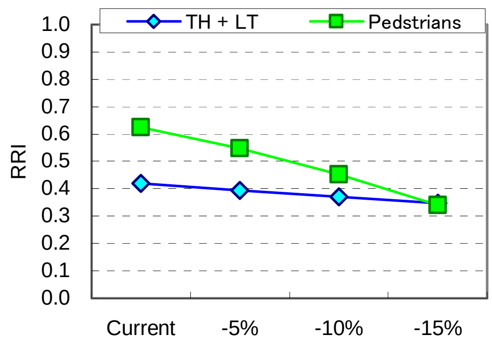


Figure 7 Scenarios of reducing delay

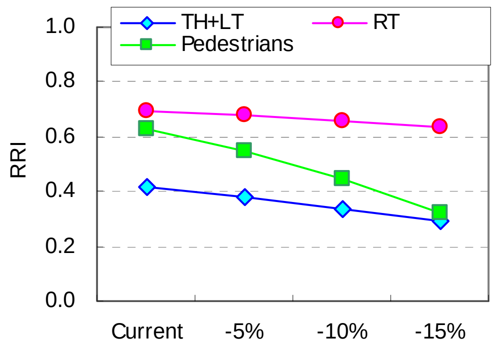


Figure 8 Scenarios of reducing both delay and PET

risk taking behaviors is tested.

Scenarios are assumed that delay would decrease by 15%, 10% and 5% compared with the current condition by shortening the cycle length. The result is shown in Figure 7.

Figure 7 shows the RRI at inter-green periods becomes lower than current condition for all users, as delay decreases. This tendency is particularly clear for pedestrians. These scenarios of shortening the cycle length have a potential to contribute to improvement in safety as well as improving capacity of left-turn flow.

On the other hand, in order to cover the capacity reduction due to shortening cycle lengths, a smaller lost time, i.e. realization of a smaller intersection is necessary. This can be realized by reducing the amount of setbacks of the stop line or by narrowing the lane widths of the crossing direction. As a result, the intensity of traffic conflict becomes greater and scenarios for them can be expressed by setting smaller PET values. So scenarios are here assumed that both delay and PET would decrease by 15%, 10% and 5% compared with the current condition at the same time. The result is illustrated in Figure 8. As for TH+LT movements, it is found that these combined scenarios have more impacts on decreasing RRI than the scenarios decreasing delays only.

7. Conclusions

The conclusions of this paper can be summarized as below:

1) A framework for evaluating cycle length of traffic signal control incorporating risk management concept is proposed.
2) Risk incidents at inter-green periods, for drivers, pedestrians and cyclists are analyzed by using field survey data and risk-taking behaviors for each user are expressed by disaggregate logit model.
3) Via a sensitivity analysis applying the estimated models, the impacts of cycle lengths and intersection size on risk taking behaviors is demonstrated.

It is clear that the models estimated this time are still not very satisfactory in particular for pedestrians and cyclists because of the number of samples. Further detailed analyses on user's behaviors are expected, by enriching the number of data at more intersections. The application of the image-processing technology enables the more effective and precise work on the data analysis and is currently under development by the authors.

Future necessary steps of this study are as follows: After a more detailed risk analysis, weights among various users will be investigated, considering the traffic composition at each intersection. By applying our approach not only to inter-green periods but also the other signal steps, it becomes possible to evaluate cycle lengths considering conflicts as well as delay, which is the conventional evaluation index of traffic signal settings. Considerations of the other restrictions such as requirement of minimum pedestrian green time and intersection capacity restriction are also necessary at that time. Then, cycle lengths will be optimized from the viewpoints of user's perception.

References

Allen, B.L., Shin, B.T., and Cooper, D.J., 1978. Analysis of traffic conflicts and collision, Transportation Research Record, 677, 67-74.

Hayward, J.C., 1972. Near-miss determination through use of a scale of danger, Highway Research Record, 24-34.

Gettman, D., and Head, L., 2003. Surrogate Safety Measures From Traffic Simulation Models, Final Report, Federal Highway Administration, 68-84.