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A MODEL TO ESTIMATE RIGHT ANGLE ACCIDENTS AT SIGNALIZED INTERSECTIONS

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ABSTRACT: Right-angle accidents are considered to be the most dangerous of all types of intersection accidents due to their high severity. In depth investigation of accident occurrence could be a valuable means of mitigating these accidents. Based on the relationship between the distribution of disturbance near intersections and drivers reactions, this study illustrates a microscopic model to enumerate the liaison between right-angle accident frequency and some explanatory variables that represent both traffic flow and intersection design characteristics. The model explains the mechanism of right-angle accident occurrence and could be used to assist safety management agencies to devise countermeasures aimed at drivers, vehicles and the physical environment. This model provides a unique tool to integrate with driver information and vehicle safety support system to decrease driving mistakes and assist in making complex judgments at intersections in general.

1. INTRODUCTION

The severity of right-angle (RA) accidents elevates their importance to traffic safety professionals. For example, right angle accidents account for 39% of fatal and 44% of injury accidents at signalized intersections in Tokyo prefecture (IATSS 1999), the setting for the data used in this study. According to a study conducted by the Institute for Traffic Accident Research and Data Analysis (ITARDA 1998), although RA accidents are only 11-13% of total crashes, they account for 26-30% of vehicle-to-vehicle angle accident at signalized intersection in Japan. These striking features point to a need for undertsanding the microscopic nature of the right-angle acident occurrence mechanism in order to develop appropriate countermeasures to increase safety at signalized intersections.

Retting et al. (1995) and Hauer et al. (1988) classified the intersection vehicle-to-vehicle accidents into 15 types according to vehicle movements before collision. This classification provides microscopic details of vehicle-to-vehicle accident frequencies. This study adopted the defition of RA accident where two through vehicles from adjacent approaches collide with each other, in effect where one vehicle has run the red light. Other Red Light Running (RLR) crashes due to right turn or left turn signal violation are not consided for this research.

Recent development of RLR crash research reveals some interesting insights of implementation of red-light camera and its influence on crash reduction techniques. Previous work emphasized the characteristics of red-light runners (Retting 1996 and Baguley 1998) and influence of several controling factors on RLR crashes and engineeringing countermeasures (Retting 1998). Although the RLR crash analysis has developed in last two decades, very few studies have provided a deeper understanding of relationship between geometric, traffic environment variables pertaining to RA accidents. Polanis (2002) highlighted the likeliness of right-angle accident when traffic signals are in red-yellow flash during late-night/early-morning hours. A separate study (Bamfo & Hauer 1997) noted that the expected number of right-angle accidents are 15% higher with fixed-time control approaches than that of vehicle-actuated control although the study did not confirm the explicit reason of the differences. Highway Safety Information System (HSIS 2000) developed a negative Binomial model to examine the effects of intersection charecteristics on RLR crash frequencies. However, the HSIS model neither incorporated the human factors involved in RA crashes nor clarified the microscopic details of the mechanism of accident occurences.

Urban drivers' psychology at or near the intersection adds a new dimension of complexity to the efforts of searching for controlling factors for right-angle crashes. An experiment underlying the mechanism of visual search (Miura 1992) shows that in demanding situations, especially in crowded intersections, a driver's functional field of view becomes narrower and hence reaction time for detecting relevant objects becomes longer. Research results of eye-marker studies (Hills 1979) found that drivers average only three fixations per second. Therefore, complex visual tasks while approaching to intersection change the range of perception-reaction time (PRT) depending on the complexity of the solution and driver's expectancy of the hazard (Bates 1995). Finally, the combination of unanticipated geometric and traffic related factors leads to increase drivers' mental load, which ultimately causes a severe right-angle accident at intersections.

Another characteristic often ignored by the RLR crash researcher leads to a specification error of RA accidents at signalized intersections. A vehicle which runs the red-light (say 'main or obstacle vehicle') always possess higher probability of accident involvement compared to the 'cross-street vehicle'. Thus, different set of variables are responsible for the different vehicles involved in right-angle accidents.

This study explicitly considers these two unique facts, human factors and the microscopic detail of the accident occurrence mechanism, while developing a new approach to estimating the probabilities of vehicle-to-vehicle right-angle accidents at four-legged signalized intersections. The purpose of this study is to develop a right-angle accident model to estimate the expected risk of RA accident based on data for 190 signalized intersections in Tokyo prefecture. Several insights will be investigated, establishing a relationship between the frequency of collisions and various geometric and traffic related environment and considering the interaction of the perception and reaction behavior of the two involved drivers. Finally, there are some suggestions on how this model of accident risk might be used to reduce the probability of severe right-angle accidents at four-legged signalized intersections.

2. NATURE OF RIGHT-ANGLE ACCIDENTS

The key criterion for developing a microscopic model is to analyze the data of right-angle (RA) accident, which lays the foundation of microscopic details of collision occurrence mechanism. A database of 190 four-legged signalized intersections in Tokyo prefecture for the period of 1992 to 1995 was used. This database was selected from an initial one of 457 intersections by considering the most dominant intersection geometry (91% accident occurred at four-legged intersections) and number vehicles in right-angle accidents (only 3% are multi-vehicle RA accident). To increase model efficiency, this study includes data from 36% black-spot intersections and which has proportional representation from the various land use pattern associated accident. For example, 52% RA accidents occur in commercial area compared to 34% in residential areas and 12% industrial zone. This representation was reflected in the database.

Careful review of the data revealed the feasibility of addressing fundamental issues of model development for RA accidents. Table 1 illustrates some basic characteristics of accidents that helped to develop important assumptions and to assess controlling factors involved in RA accident. As seen, most of the RA accidents occurred on signalized approaches and in terms of signal phase, with about 60% percent crashes take place at two-phase signal control. Red-running accident rate is not a simple function of major road flow (Baguley 1988) and hence local streets experience a significant proportion of RA accident. Risk for cross street vehicle from the left seems higher than that for the right. A similar conclusion was also derived by Campbell et al. (1970) who reported that 60.3% of the vehicles violated the stop sign facing from left approach. Figure 1 portrays the graphical representation of basic characteristics RA accident. The results section further describes the associated factors in detail in interpreting the model outcome.

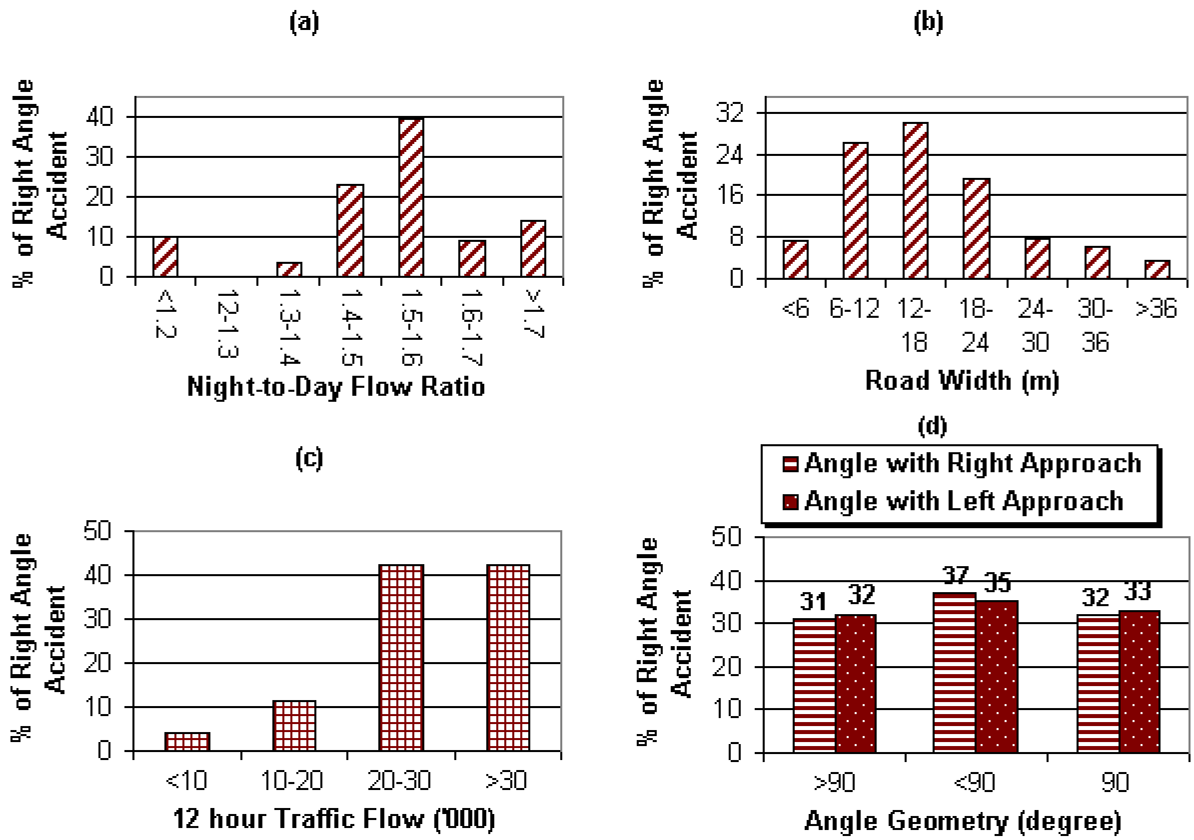

Figure 1: Several Factors that Affects Right-Angle Accident

Table 1: Basic Facts of Right-Angle Accident at Signalized Intersections

Signal Control Type	Two-phase	Three-phase[1]	Multi-phase
	60%	29%	11%
Road Type	Local Street	Prefectural Road	National Road
	46%	31%	23%
Land Use	Commercial	Residential	Industrial
	52%	34%	14%
Intersection Approach Angle	$>90^0$	$<90^0$	90^0
	32%	35%	33%
Approach Type	Major Road	Minor Road	
	62%	38%	
Vehicle from	Right[2]	Left	
	41%	59%	

Notes: 1. An extra phase for right or left turn; 2. Right-hand driving in Japan

3. MIROSCOPIC ACCIDENT MODELING

Figure 2 depicts the conceptual diagram of the RA accident occurrence mechanism at signalized intersections (see theoretical detail in Karim et. al. 2001). RA accidents occur in some circumstances when the decision can be different depending on instantaneous speed and the position of 'main' vehicle at the onset of amber or beginning of red light. Consequently, the 'cross-street' vehicle attempts to decelerate and avoid red-light runners within a short time. Depending on the perception-reaction time (PRT) and decision of either to stop or run-the-red, the main vehicle is transformed into the 'obstacle vehicle' in emerging as a 'disturbance' for the cross-street vehicle.

The concept of this model is that each vehicle carries a certain portion of the 'total risk' probability of right-angle accident. This key consideration was not the focus of previous research since, from the police accident investigation to the prosecution of the offence, each system pertaining to a crash makes an effort to identify the 'main' offender. With the "proportional risk" concept, multiplying the individual probabilities, which are assumed independent of each other, provides the total right-angle accident risk. To simplify the task of modeling, only two vehicle crashes are considered for the analysis.

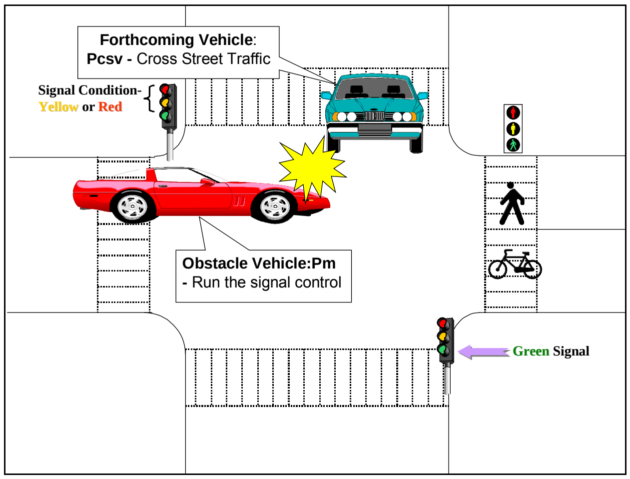

Figure 2: Mechanism of Right-Angle Accident Occurrence

Depending on the situation, the main vehicle driver could react in three different ways: gradually decelerate before the stop line to be on the safe side, stop the vehicle by sudden braking or continue the current speed or speed-up to 'beat-the-red'. The latter action carries the possible risk of RA accident while second action increases the risk of rear-end accidents. Apparently, the main vehicle possesses the higher probability of risk, being a principal contributor to RA accident.

In contrast, the cross-street vehicle driver's choice is restricted by the position and speed of main vehicle. In this situation, the driver could decide to 'stop' the vehicle by sudden braking or stay on the collision course due to insufficient time. The first action leads to a rear-end crash with the following vehicle behind. Conversely, insufficient time and intersection geometry may not allow the cross-street vehicle to detect the 'disturbance' that increases the risk of a right-angle accident. Obviously, the probability of a 'cross-street' vehicle incurring an accident will be much lower compared to main vehicle that breaks the law. The results of microscopic model also support the different 'weights' of probability for different vehicles involved in accident.

Derivation of the probability of main vehicle depends on the frequency of signal changes, types of signals and phases, and geometric characteristics that influence a driver's 'stop-or-go' decision. It is reasonable to assume that occurrences of such 'disturbances' follow a Poisson process. Manner and Kilareski (1998) suggest that time intervals between acceleration or deceleration-inducing disturbances are exponentially distributed. After simplifying the exponential density function, the probability of cress-street vehicles encountering a main vehicle that corresponds to at least one disturbance occurs within specified time period becomes

[1] $$P_m = 1 - e^{-e^{\alpha X}}$$

where α and X represent estimation coefficients and explanatory variables of disturbance frequency respectively.

From the cross-street vehicle driver's point of view, perceiving unexpected obstacles depends on the number of vehicles approaching a red or yellow light from the main approach and the quality of their response, as well as the geometric configuration of concerning approach. This distribution of gaps is determined by volume and platooning characteristics of the conflicting street approach. However, RA accident frequency is not directly proportional to cross-street volume (Baguley 1988). Available gaps represent required perception-reaction time that can be assumed as Weibull distribution due to its good approximation of Normal distribution (Abernethy 1996). Conversely, required perception-reaction time varies with driver characteristics, intersection geometry and traffic conditions (Bates 1995) but can again can be assumed as Weibull distribution. Integrating both perception-reaction distribution and related explanatory variables using an exponential distribution generates the probability of cross street vehicles avoiding an RA accident

[2] $$P_{csv} = \frac{1}{1+e^{-\beta Y}}$$

where β and Y represent estimation coefficients and explanatory variables respectively.

Finally, the right-angle accident probability can be achieved by multiplying the probability of cross street vehicle encountering main vehicle (Equation 1) and probability of cross street vehicles avoiding the accident (Equation 2). It can be assumed that both events are independent of each other. The expected number of RA accident can then be estimated multiplying the right angle accident probability by the through traffic volume of the approaching street.

For estimation purpose, the Poisson distribution has been commonly used in modeling the temporal variability in accident frequency at a given location (Miaou et. al. 1994) due to its non-negative, discrete and random features. However, it has only one parameter, and this requires that the expectation and variance be equal. As accident counts over space are likely to be overdispersed, the applicability of a Poisson model is questionable for modeling spatially variability. In any event, the choice between the Negative Binomial model and Poisson model can largely be determined by the statistical significance of the estimated coefficient α or β (Poch and Mannering 1996). The Negative Binomial distribution was used in this study since the Poisson, even if it were valid, is a special case of this distribution. The models were estimated by standard maximum likelihood methods.

Several types of variables were examined in the analysis, including main and cross street flow, right or left-turn volume on entering approach, total flow of opposing approach, lane configuration (crossing approach width, lane restriction and sharing information, exclusivity of right-turn lane), intersection geometry (approach curvature, angle between the approaches, sight distance, elevation of structures, presence of median or driveway), traffic control type (e.g., length of red, phase types), and vehicle driver characteristics (e.g., functional field of view). The Negative Binomial model explored the relationship between RA accident and explanatory variables by estimating goodness of fit, coefficients, predicted values, and the t-value for each variable.

4. MODEL RESULTS

Tables 2 and 3 show the model estimation results. After considering 74 variables that were collected during the site survey, only 22 were found relevant in terms of statistical significance tests, logic of model development and the knowledge from the literature review. Of these, 13 variables had an impact on the probability of main street vehicles being involved in an accident and 9 variables affected the same probability for cross-street vehicles. The average probability for the cross-street vehicle is lower than for the main street vehicle as explained earlier. A positive sign corresponds to an increasing effect on RA accident probability whereas a negative represents a decreasing effect. All parameters are statistically significant at the 10% level.

In interpretating the results the peculiar nature of Tokyo’s transport infrastructure facilities should be taken into account. Tokyo is a highly congested city with many elevated structures (like expressways and pedestrian overpasses), which might shadow an entire intersection. In general, traffic safety was not major concern during the design and construction of transport infrastructure in 1970’s. Below is a discussion of the model relationships for individual variables.

4.1. The effect of traffic flow

RA accidents show a unique relationship with traffic flow compared to other types of accidents at signalized intersection. As noted earlier, Baguley (1988) hypothesized that the red-light running rate is not a simple function of major flow. The higher ADT on cross-street, and the fewer the number of gaps available, the higher is the chance of a 'main' vehicle encountering 'cross-street' vehicle. Four types of traffic flow and their impact on RA accident were explored in the analysis. Higher right-turns seemed to be associated with reduced RA accidents since as a major part of right-turn flow diverts from the through flow, thereby decreasing the chance of becoming an obstacle for the cross-street traffic flow. Increased total flow of the subject approach has a positive effect on RA accident risk, which has been confirmed by the HSIS (2000). On the contrary, higher cross-street flow (cross-street left and right traffic flow) results in lower headway and hence higher chance of encountering an obstacle vehicle. Other researchers reported the identical results regarding cross-street flows. Figure 1(c) is a graphic representation of the effect of cross-street flow on RA accident risk.

4.2. The effect of lane configuration

The effects of three types of lane configuration were explored. As the right turning maneuvering takes significant time, the right turning vehicle approaching at intersection from the combined through and right lane will have slowed down; consequently a following vehicle proceeding through the intersection will visualize the right turning vehicle as an obstacle and would move to an exclusive through lane if available, increasing accident risk. The effect of road width on RA accident is more complex and discordant. Figure 1 (b) depicts the effects of road length on the observed right-accident frequency distribution. Road length greater than 24m does not significantly affect RA accident risk. The estimation results of this variable should be explained cautiously, especially for highly congested city like Tokyo where streets greater than four lanes are rare. HSIS suggests the effect is probably a combination of the width of the cross-street and cross-street volume. On the other hand, the existence of an exclusive right lane reduces right angle accident likelihood as a result of the smooth maneuvering of right-turning vehicle. Right-turn pocket also reduces the probability of conflict at the intersection approach for through traffic vehicle by decreasing through traffic volume in individual through lanes (Datta 1991).

Table 2: Model Estimation Results: Variables Affecting the Probability of Encountering Main Vehicle

Parameters in Model	**Coefficient**	**t-value**
Constant	-1.924	-3.043
Combined through-right, right turn drop lanes and two or more lanes on the approach (1 if there are two or more combined through-right or right-turn drop lanes, 0 otherwise)	0.981	1.84
Right-turn restriction (1 if right –turns is restricted, 0 otherwise)	1.101	2.21
Angle of road in between two adjacent legs (1 if two adjacent legs contain an angle road in between them, 0 otherwise)	1.977	4.99
Curvature on approach leg (1 if curve on approach, 0 otherwise)	0.207	1.65
Pedestrian overpass leg at the corner (1 if pedestrian leg exists, 0 otherwise)	0.964	2.91
Intersection sheltered by elevated road (1 if one direction is under an elevated road, 0 if no elevated roads above)	1.81	3.98
Central road median (1 if wider than 2 meters, 0 otherwise)	0.524	1.92
Intergreen period on current leg (1 if period longer than 3 sec, 0 otherwise)	-1.352	-2.68
Right approach road width (in meter)	-0.048	-1.97
Right-turn volume in thousands (4 years) of the current approach	-0.077	-1.80
Through traffic volume in thousands (4 years) of the cross-street approach	0.075	2.31
Through traffic volume in thousands (4 years) of current approach	0.076	2.52
Right-turn volume in thousands (4 years) of the opposite approach	-0.059	-4.66

4.3. The effect of traffic control

The influence of the length of the change interval (intergreen period) on red-light running has been extensively studied (Retting and Greene 1997 and Chin 1989). Change interval consists of a 'steady yellow signal warning of an imminent change in right-of-way that may be followed by an all-red phase during which traffic approaching the intersection is required to stop'. A negative sign of intergreen period variables in this analysis confirmed the similar conclusion of previous research that longer change intervals can reduce RA accident risk.

The variables indicating protective right turn, permissive right-turn or combined left and right restriction have different effects on RA accidents for different types of driver. Results show that if the major approach has protected right turn, RA accident risk tends to increase due to high resulting trough traffic. On the contrary, Poch and Mannering (1996) reported a decrease in total accidents with right-turn restriction. Similarly, for the cross-street vehicle, if there are more right-turn lanes, the existence of the right-turn permission may be difficult to ascertain by opposite through vehicle drivers; thus the average available PRT should be shorter, thereby reducing the chance to avoid failure. The local street variable is a composite variable representing the combination of the low ratio of minor-to-major flow, longer red times and low traffic volume. HSIS hypothesized those long red phases, coupled with low crossing volume may cause red-light crashes for fixed time signals. Results of this analysis verified the hypothesis, as evidenced by the positive sign for the relevant coefficient.

4.4. The effect of Driver and vehicle characteristics

The idea of functional field of view (Miura T., 1992) was adopted in this study depending on number of disturbances and angle of clear view from 30m away from the edge of current approach. The coefficient sign indicates that functional field of view reduces RA accident frequency. Absence of narrower vision or turmoil enables a driver to detect the main vehicle easily and consequently reduces the probability of RA accident occurrence for the cross-street vehicle driver. The variable, large vehicle ratio represents greater perception and reaction time required by the large vehicle drivers to avoid a right-angle accident collision. It takes heavy braking within insufficient time to avoid the red-light runners. The positive sign of the relevant coefficient confirms this problem.

Table 3: Model Estimation Results: Variables Affecting Cross-street Vehicle Failure Probability

Parameters in Model	**Coefficient**	**t-value**
Constant	-15.572	-30.64
Existence of driveway (1, if driveway exist, 0 otherwise)	0.138	1.69
Angle between entering approach and opposing approach (1 if the angle is less than 15^0, 0 otherwise)	-0.591	-1.96
Exclusive right lane (1 if there exist exclusive right lane, 0 otherwise)	-0.342	-1.91
Permissive right turn (1 if permissive right turn, 0 otherwise)	-2.115	-5.95
Right-turns not aligned and not single lane approach, protected right, or stop control (I if right turns are not aligned and the approach does not have a single lane, protected right, or stop control, 0 otherwise)	-0.164	-1.71
Local street approach (1 if local street with traffic less than 10,000 approach and long red time, 0 otherwise)	0.881	2.95
Large vehicle ratio of current leg	0.053	2.80
Functional field of view (1 if angle of clear view is less than 10 degree or any kind of disturbances exist in opposite side of current leg)	-0.702	-2.64
Night-to-day traffic flow ratio	1.382	1.92
Overall Estimation Results (Sample Number 746 out of 760)		
Log likelihood at convergence	293.13	
Log likelihood with constants only	921.8	
Likelihood ratio Index	0.682	
Reciprocal of Negative binomial Dispersion Parameter ($\theta=1/\alpha$)	0.708	4.58
Average probability of encountering a main vehicle (P_m)	0.159	1.64
Average probability of the failure of cross-street vehicle driver (P_{csv})	$5.25*10^{-6}$	3.49

After reviewing data for 19 intersections, Polanis (2002) concluded that right-angle crashes are more likely during the period of low traffic volume with flashing signal in operation. The variable night-to-day traffic flow ratio reflects increased perception time at night and increased driver failure probabilities to avoid RA accident risk. Due to time constraints flashing signal operation data are not included in the analysis.

4.5. The effect of geometric variables

Seven of eight geometric variables were statistically significant for the probability of encountering a main vehicle. The angle between the adjacent right or left approach is the best predictor of RA accident risk. It creates a situation for increased speed by the main vehicle as the greater angle between the approaches causes a visual impediment to determine the existence of cross-street vehicle. After studying several signalized intersection types, Hall (1986) concluded that intersection accidents were likely to increase with angles greater 105 degrees between the adjacent legs. Having an angle of the entering approach and opposite approach presents more complexities than a regular-shaped intersection. Model results indicate that such angles less that 15 degrees assist cross-street vehicle driver to visualize the intersection disturbance with less available PRT, thereby reducing the risk of collision with the main vehicle.

Four geometric variables capture obstruction of vision effects: the pedestrian overpass legs at the corner, the elevated structures, the approach curvature and central road median. Instead of using a single sight distance restriction variable, this study explored the microscopic detail of each element that obstructs driver vision near an intersection. In Tokyo, intersections with poor design of pedestrian overpasses experience a high frequency of right-angle accidents. Pedestrian legs exactly at the corner restrict driver vision requiring more time to decide whether to stop or go at the onset on amber. Sight-distance restriction could also occur due to horizontal or vertical curvature across the intersection. The positive sign for the relevant variable confirms similar results obtained by Poch and Mannering (1996). That study hypothesized that a restriction created by an object on the median would be realized when the largest identifiable gap of the main approach traffic is not adequate to provide the right-turning vehicle time to identify the gap and complete the maneuver. Similar principles could be applied to the main vehicle to detect the existence of cross-street vehicle. Due to land resource constraints in Tokyo, most of the elevated circular expressways are built over the urban streets. If an elevated road shelters an intersection, the darkness delays the perception of through vehicles in the intersection and hence increases the likelihood of RA accident frequency.

Existence of driveways near the intersection approach creates disturbances that affect safety positively for the cross-street vehicle driver. This is because unexpected emergence of vehicles from driveways near an intersection causes the left lane through traffic vehicle driver to perceive the position of main vehicle.

5. SUMMARY AND CONCLUSIONS

Using a negative binomial model, this study estimated the right-angle signalized intersection accident risk as distinct from models that estimate accident frequency. In so doing, the effects of explanatory factors in the model can be used to develop efficient measures to improve intersection traffic safety. Several interesting insights were obtained during the course of model development. First, in portraying the microscopic view of intersection accidents, it was found that involved vehicles possess different risk probabilities that are affected by different sets of variables. Second, it appears that poor signal design coupled with complex geometric design is a principal contributor to the right-angle accident risk at signalized intersections. Third, a close examination of the effect of the entering flows reveals that right angle accident risk does not seem to strongly depend on larger of the traffic flows. Depending on data availability of explanatory variables, this model may be transferable to any other location at signalized intersections. Current research is testing this hypothesis. Using this model formulation others types of RLR accidents might be modeled as well. In addition, the microscopic mechanism presented could be an important theoretical foundation for exploring the effects of innovative measures such as intelligent traffic safety warning systems for improving right-angle collision safety at urban intersections.

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