Risk Evaluation Model for Traffic Accident at Four-legged Signalized Intersections

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Abstract:

Opting the arm-base approach, this study develops the logic for the most frequent types of angle accident at four-legged signalized intersections. Microscopic analysis of the vehicle movements is developed considering the occurrence of an angle accident having two indispensable premises – one is the encountering of an obstacle vehicle, and other is that the forthcoming vehicle driver failed to avoid the collision. Based on the relationship between the disturbance and drivers reactions, this study illustrates several models to enumerate the liaison between accident frequency and some explanatory variables which covered both flow and design characteristics of the intersection using Negative Binomial to counter the overdispersion issue usually discerned in accident data through maximum likelihood estimation of the parameters. The upshots of the models exhibits the influence of certain variables on angle accident which fruitfully explain the mechanism accident and assists to take certain meticulous countermeasures against that types of accident at intersection. The accident risk models allow the management to handle the high-risk as well as normal intersection successfully to lessen the accident frequency and continuously monitoring of this urban malaise.

Key Words: Intersection accident, Microscopic modeling, Angle accident, Negative Binomial Model.

1. INTRODUCTION

The invention of automobile brings some demerits and among them the most perilous and aching is traffic accident. Urban areas and intersections have the highest population-based rates of both injury and property-damage crashes. The problem of traffic accident in Japan is still serious and far from the satisfactory level because total accident cost is still high (about 5.03 trillion yen in 1994) although the fatal accidents decreasing in recent years. According to IATSS's statistics in 1999 the total number of traffic accident is about 98 times and injuries are 121 times higher than death even after controlling the vehicles and investing a huge amount of money, which suggests that greater attention should be focused on reducing the number severity of crashes in urban environments.

About 58.4% accident of total and 45.2% fatality at intersection (in 1999) elevate the importance of intersection accident where most frequent accident type is right-turn accounting 25% to total followed by rear-end type (24%). Right-angle accident suffers the worst records having 33% fatality and 45% of left-turn accident was involved with motorcycle accident. These striking features invigorate to enliven the microscopic model for these types of uninvestigated angle accident.

Efforts to reduce the number and severity of intersection crashes have been hampered by a lack of information about types of crashes (Rattering et al, 1995) and the recognition of the mechanism of accident occurrence (Wang Y., 1998). Although clearly identifiable blackspots have been removed from the Japanese highway system, but recent increase of intersection accidents (specially vehicle-to-vehicle angle accident increase 16.1%) indicates that conventional countermeasures are not effective in reducing certain types of intersections accidents and new comprehensive countermeasure against traffic accidents are urgently required ("Five-year", 1996).

Models to estimate the probability of three types of vehicle-to-vehicle angle accidents of four-legged signalized intersections on the basis of arm-base microscopic approach considering the occurrence of disturbances and drivers reactions are provided in this paper. They are based on the data from 190 intersections in Tokyo prefecture, which includes blackspot intersections, identified by ITARDA. Several insights will be investigated establishing a relationship between the frequency of collisions to various geometric and traffic related environment considering the interaction of two vehicles drivers' perception and reactions behavior. Against this background, the classifications are reviewed to illustrate the impacts of types of accident for microscopic model development. Finally, there are some suggestions on how the status of intersection knowledge's might be improved and hence reduce the probability of some severe angle accidents at four-legged signalized intersections.

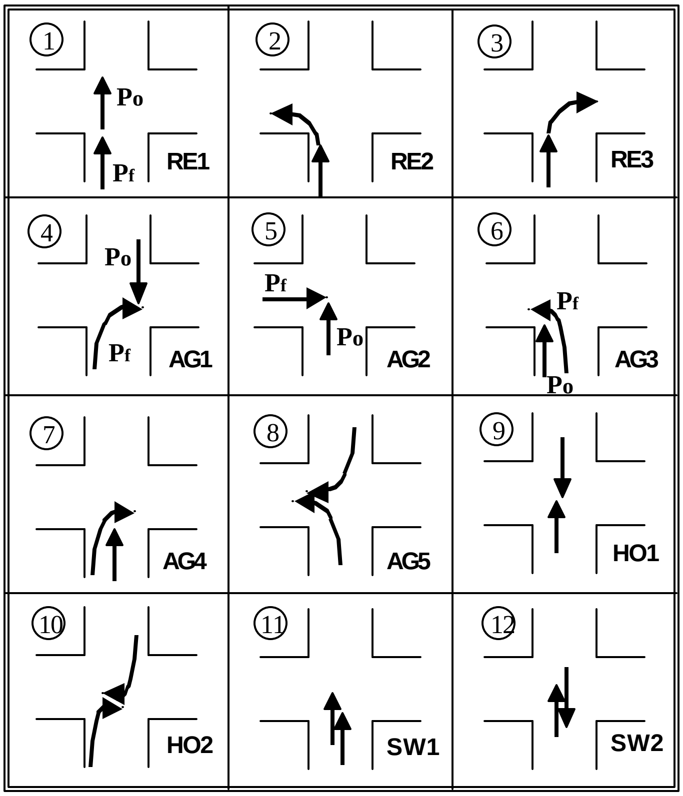
2. MICROSCOPIC ACCIDET MODELING

Most of the previous researchers have attempted three approaches to relate accidents to geometric characteristics and traffic related explanatory variables: Multiple Linear regression, Poisson regression and Negative Binomial regression. The research on traffic accident shows that multiple linear regressions suffer some undesirable statistical properties when applied to accident analysis (Jovians and Chang, 1986). Minou et al. (1992) used a Poisson regression model, which discovered the Poisson model limitations that the mean and variance of the accident frequency are equal. In most accident data, the variance of the accident frequency exceeds the mean and the data would be overdispersed. Minou (1994) and Shankar et al. (1995) have addressed the overdispersion issue by using Negative Binomial regression.

All the previous studies related to intersection did not consider the arm-base approach. Poch et al. (1996) and TRL (Transport Research laboratory) in Great Britain (Hall R.D., 1986 and later Maher M. J. et al. 1996) conducted arm base approach to predict the accident frequency on intersections of principal arterial and concluded that negative binomial regression is a powerful predictive tool and arm-base approach reveals many unknown characteristics of intersection accident frequency which could lead to design the improvements and remedial measures. Based on the microscopic analysis, Wang Y. (1998) studied the vehicle movements having two indispensable premises – one is the encountering of obstacle vehicle, another is response failure of the forthcoming vehicle driver. But all these previous studies did not develop successfully which can explain the general recognition of angle accident at intersection. This research advanced a reasonable method for developing intersection angle accidents.

2.1 Accident Classification by Pattern

Several researchers try to classify urban accident in different ways. Among them the most common is categorization by initial impact type in intersection safety analysis. If, however, to understand and analyze accidents at intersections, it is better to reclassify accidents in order to relate them to the flows to which the two colliding vehicles belong. Electro-Mechanics Department of General Motors Research laboratories started accident classification in 1968 (Perkins et al.), which seeks to analyze the interaction of the driver, vehicle, and roadway at intersections, in order to determine detectable measures of traffic characteristics that could develop into accidents. Hauer *et al* (1988) and Rettering et al. (1995) classified vehicle-to-vehicle accidents at signalized intersections into several patterns based on precrash driver/vehicle behavior that would provide information about the most common circumstances associated with urban crashes.



Notes: RE-Rear End; AG-Angle; HO-Head on Collision; SW-Side Sweep
Po-Obstacle Vehicle; Pf-Following Vehicle
AG2-which vehicle breaks the law becomes obstacle vehicle

Figure 1: Intersection Accident Classification

Most useful intersection classification developed by Wang Y. (1998), which is taken as an accident classification standard in this study with little modification. The main concept of this classification is that the causal factors for different kinds of accidents, and therefore grasps the relationship between accident risk and accident causal factors. To demonstrate the imprecision of this type of analysis, Figure 1 shows twelve patterns of intersection vehicle-to-vehicle accidents, which reveals that more than half of the accidents arose from angle accidents AG1, AG2 and AG3. This led to the conclusion that for details insights of intersection accidents it should be classified to the flows to which the two colliding vehicle are approaching towards the intersection. Further, to understand and analyze accidents at intersections, it is better to use the "vehicle maneuver" entry from the police accident report.

2.2 Angle Accident Modeling and Its Importance

Most of the previous research on angle accident relates the effects of signal installation and signal phasing to accident frequency. Datta (1994) investigated the impact of traffic signal installations on accident characteristics. Hauer (1992) and Persaud (1992) modeled the safety of signalized intersections on the basis of traffic flow and accident history. Upchurch (1994) compared five types of right-turn phasing with right-turn accident. Maher M.J (1996) and Wang Y. (1998) develops model available for right-turn accident only using the technique of generalized linear models and nonlinear regression respectively. But none of these studies highlights the details of angle accident mechanism, which could explain adequately to alleviate such types accident at intersections. Based on the relationship between the disturbance and drivers reactions this study illustrates several models to enumerate the liaison between angle accident frequency and some geometric, road environment and traffic related factors.

3. MODELING METHODOLOGY

For angle accident, it is more important to concentrate the behavior of driver coming from different approach and their reactions subjected to surprising situations in an unexpected traffic situation at intersection. Experiment underlying the mechanism of visual search shows that in demanding situations, especially in crowded intersections, driers process deeper at each fixation point, that is, they are more attractive. Therefore the functional field of view becomes narrower and hence reaction time for detecting relevant objects becomes longer (Miura T., 1992). Finally the combination of unanticipated geometric and traffic related factors led to increase drivers mental load, which ultimately causes a severe angle accident at intersections.

The Mechanism of Accident Occurrence

The random causal factors (“noise”, ”disturbance”) had a decisive effect on accident occurrence at a microscopic level. Despite the specifics of different accident types, the occurrence of accidents is considered to be based on two premises in this study, one is the encountering of an obstacle vehicle, and the other is that the forthcoming vehicle driver failed to avoid collision. Obstacle vehicle are usually due to emergence of “disturbances”. A disturbance here is defined as anything that interrupts the smooth movement of traffic flow. If the mergence of a disturbance has caused the deceleration or sudden braking of leading vehicle, then the leading vehicle become an obstacle for the following vehicle, which as to adopt some steps to avoid the collision. If the following vehicle driver fails to avoid the collision, an angle accident will occur.

If the probability of meeting an obstacle vehicle is denoted by P_o, and Pf denotes the probability of the corresponding driver failed to avoid the collision, then the probability of this driver to be involved in an accident is the product of P_o and P_f, as they are normally independent. That is:

$$P_{risk} = P_o \cdot P_f \tag{1}$$

As the exact form of Po and Pf is unknown, empirical log link functions are adopted as follows

$$\ln(P_o) = \mathbf{f}\grave{\mathbf{A}}_{\mathbf{o}}\mathbf{x}_{\mathbf{o}} \quad \text{and} \quad \ln(P_f) = \mathbf{f}\grave{\mathbf{A}}_{\mathbf{f}}\mathbf{X}_{\mathbf{f}} \tag{2}$$

The angle accident risk

$$\ln(P_{AG_I}) = \hat{\mathbf{a}}_{\mathbf{o}}\mathbf{x}_{\mathbf{o}} + \hat{\mathbf{a}}_{\mathbf{f}}\mathbf{x}_{\mathbf{f}} = \hat{\mathbf{a}}\mathbf{x} \tag{3}$$

where $\boldsymbol{x}$=($\boldsymbol{x_o}$, $\boldsymbol{x_f}$) are vectors of explanatory variables for P_o and P_f respectively and **â**=(**â**$_o$,**â**$_f$) are the vectors of the corresponding unknown parameters to be estimated and P_{AGi} = Average angle accident risk for AG1, AG2 and AG3. To simplify the problem, it can be assumed that all the vehicles using the leg in certain time period have the same accident risk. Then, number of accidents that occurred within this flow complies the Binomial Distribution

$$P(n) = \binom{f}{n} P_{AG_I}^{n} (1 - P_{AG_I})^{f-n} \tag{4}$$

where f : through opposite leg traffic volume for AG1 and entering leg through traffic volume for AG2 and entering leg left-turn for AG3; n: number of accidents occurred. Since an accident is very rare case, P_{AGi} is normally very small and traffic volume f is very large, Poisson distribution is a good approximation to binomial distribution:

$$P(n) = \frac{m^n \cdot \exp(-m)}{n!} \tag{5}$$

with Poisson distribution parameter $m = E(n) = f \cdot P_{AG_i} = f \cdot \exp(\hat{\mathbf{a}}\mathbf{x})$ (6)

Poisson distribution has been commonly used in predicting accident number (Miaou *et al*, 1992) due to its nonnegative, discrete and random features. Poisson model, however, has only one parameter, and this requires the expectation and variance to be equal. As most accident data are likely to be overdispersed, the applicability of a Poisson model is therefore limited. An easy way to overcome this difficulty (i.e. the mean must be equal to the variance) is by adding an error term, å to the link function as shown by Formula (7) $\ln m = \ln(fP_{AG_i}) + e$ (7)

Assume exp(å) is a Gamma distributed variable with mean 1 and variance*á*. Substituting *m* in Formula (4) by Formula (7), we have

$$P(n \mid e) = \frac{\exp(-fP_{AG_i}\exp(e)) \cdot (fP_{AG_i}\exp(e))^n}{n!} \tag{8}$$

Integrating åshown in equation (10), negative binomial distribution is derived as:

$$P(n) = \frac{\Gamma(n+q)}{\Gamma(n+1)\Gamma(q)} \left(\frac{q}{f \cdot P_{AG_i} + q}\right)^q \left(\frac{fP_{AG_i}}{f \cdot P_{AG_i} + q}\right)^n \tag{9a}$$

where $q = 1/a$. In general Formula (9a) can be written as

$$P(n_{jkl}) = \frac{\Gamma(n_{jkl}+q)}{\Gamma(n_{jkl}+1)\Gamma(q)} \left(\frac{q}{f_{jkl} \cdot P_{AG_{ijkl}} + q}\right)^q \left(\frac{f_{jkl}\, P_{AG_{ijkl}}}{f \cdot P_{AG_{jkli}} + q}\right)^{n_{jkl}} \tag{9b}$$

here i denote types of angle accident; j for time category (year); k for intersection code and l for leg number. Its variance is changed to

$$V(n_{jkl}) = E(n_{jkl})[1 + aE(n_{jkl})] \tag{10}$$

The choice between the Negative Binomial model and Poisson model can largely be determined by the statistical significance of the estimated coefficient *á*. Since *á* can be larger than zero, the restraint of the mean equal to the variance in Poisson model is released. Therefore, negative binomial distribution can deal with the overdispersed data. The following section emphasizes the basic concepts and the logic behind the accident model development. The key point of angle accident model is the proper identification of obstacle and following vehicle and their behavior on unexpected situation.

3.1 Modeling AG2 Accident Risk

Among the angle accident AG2 is the most dangerous accident because two vehicles are crashes each other perpendicularly one of which ran after the control. Out of two through traffic vehicle, the vehicle which is violating the traffic signals or going to continue to pass the intersection very quickly at the end of intergreen time (yellow signal) is referred as "Obstacle Vehicle" because it interrupts the smooth through traffic flow coming from left or right leg. By not yielding, obstacle vehicle causes a collision with a cross-street through traffic vehicles that is referred to as "Forthcoming Vehicle". Some preliminary survey on intersection accident classification identifies the obstacle vehicle, which is invading the red-signal or didn't try to stop when the signal becomes yellow to red. Reason behind this type of tendency is either the current leg signal time is short or emergence of disturbance or bad geometric environment of intersection which leads Po driver to complete the crossing process with comparatively longer time as he expected.

Statistics related to AG2 accident reveals the feasibility of assumption taken for the development of AG2 accident modeling (Table1). Most of the AG2 accident occurs in signalized approach. Considering signal phase, almost sixty percent crashes take place in under two-phase signal control. Compare to local street (maintained by city office and usually low traffic volume), national road or prefectural roads have higher accident frequency. Same conclusion also derived by Campbell et al. (1970) reporting that 40.3% of the vehicles violated the stop sign facing from left approach. In signalized intersection Pf vehicle coming from left approach is more (59%) then vehicle coming from right.

Table 1: AG2 type Accident Basic facts

Control Condition	Accident Occurs	Phase Control	Accident Occurs	Road (leg) Type	Accident Occurs
Stop sign (legs)	109 (43.6%)	-	-	Local Street	109
Signalized (legs)	141 (56.4%)	Two Phase	84 (59.6%)	National or Prefectural	77 (91.7%)
				Local Street	7 (8.3%)
		Four Phase	57 (40.4%)	National or Prefectural	57

Formulation of AG2 Accident Risk

For AG2 accident, red or yellow signal time and red signal itself becomes an important disturbance along with other disturbances which ultimately lead a vehicle to become an obstacle vehicle for right or left-approach through traffic vehicle. The cross-street vehicle has to deal with emerging obstacle vehicle within available PRT to avoid the collision. If P_f's driver reaction is sufficient enough, an AG2 accident is avoided; otherwise, an AG2 accident will happen.

A) Formulation of P_o: The leading vehicle's deceleration is normally caused by the emerging disturbances. As the occurrence of disturbances is discrete, nonnegative and random, it is a Poisson arrival process. If times between arrivals are independent and follow the same exponential distribution, the probability of disturbance m's happening within t_d is

$$f(t) = \lambda_{dm} e^{-\lambda_{dj} t} \qquad t>0 \tag{11}$$

The probability for obstacle vehicle becomes $P_{dm} = \int_0^{t_d} \lambda_{dm} e^{-\lambda_{dm} t} dt = 1 - e^{-\lambda_{dm} t_d}$ (12)

where λ_{dm} is the arrival rate of disturbance m; and t_d is the time difference between disturbance and leading vehicle. Since any of the disturbances can cause the deceleration of the leading vehicle, the probability encountering obstacle vehicle is identical to that of at least one disturbance occurs. Since $\sum_j^z \lambda_{dj} t_{dj} = e^{\beta_d x_d}$ should be a positive variable and should be affected by related explanatory variables, here again we adopt exponential link function to consider the effects of the variables

$$P_o = 1 - \sum_{m=1}^{z} (1 - P_{dm}) = 1 - e^{-\sum_{j=1}^{z} \lambda_{dm} t_d} = 1 - e^{-e^{\beta_d x_d}} \tag{13}$$

In Formulae (13), $\boldsymbol{\beta_d}$ and $\boldsymbol{x_d}$ are vectors of unknown parameters and explanatory variables of disturbance frequency respectively. $\boldsymbol{\beta_d}$ does not change with locations, while $\boldsymbol{x_d}$ varies from place to place.

B) Formulation of P_f: In stop-controlled approach, cross-street traffic coming from the right may pose the most immediate since the P_f's vehicle driver in this case has the least amount of time to recognize that a vehicle has ran the stop sign and thus to take evasive action. Depending on the complexity of the problem, the value of PRT (Perception Reaction Time) range changes depending on the complexity of the solution, and the driver's expectancy of the hazard (Bates, 1995). Normally there are two types of PRT: available PRT and necessary PRT.

Driver age distribution is the same for all our objective legs omitting the difference of NPRT across age, then we can assume that all driver's follows the same Weibull (α,λ) distribution

$$f(t) = \alpha \lambda t^{\alpha-1} e^{-\lambda t^{\alpha}} \quad \text{for } t>0 \tag{14}$$

If a driver has available PRT of t_{av}, P_f can be calculated by integrating Formula (14) from t_{av} to infinite

$$P_f = \int_0^{\infty} \int_{t_{av}}^{\infty} f(\lambda, t) f(\gamma, t_{av}) dt dt_{av} = \int_0^{\infty} e^{-\lambda t_{av}^{\alpha}} \alpha \gamma t_{av}^{\alpha-1} e^{-\gamma t_{av}^{\alpha}} dt_{av} = \frac{1}{1 + \lambda/\gamma} \tag{15}$$

Formula (15) shows that P_f is only decided by μ and γ, and have no relationship with ν. If λ is bigger, the expectation will be small. As the expectation of APRT is normally larger than that of NPRT, γ should be smaller than λ which implies that P_f is smaller than 0.5. Since parameter λ and γ are nonnegative variables, λ/γ can be related to various factors by an exponential link function. Corresponding Pf can be written as

$$P_f = \frac{1}{1 + \exp(-\beta_h \mathbf{x_h})} \tag{16}$$

In Formula (16), $\boldsymbol{\beta_h}$ and $\boldsymbol{x_h}$ are vectors of unknown parameters and explanatory variables respectively. Finally, replacing P_o and P_f in Formula (1), a generalized AG2 accident risk model can be derived which contains road environment and traffic regulation and human related factors.

$$P_{AG2} = P_o * P_f = \frac{1 - e^{-e^{\beta_d x_d}}}{1 + e^{-\beta_h x_h}} \tag{17}$$

3.2 Modeling AG3 Accident Risk

The key point related to AG3 accident occurrence is left-turning maneuver and lane-changing mechanism to reach on left lane for left-turning maneuver. After searching hundreds of reports and detail field observation on AG3 accident, it could be concluded that AG3 accident is probably due to left-turning vehicle on the left most lane interrupting the second vehicle's left-turn maneuvering on the right lane who decide to go left after the first vehicle. So based on precrash actions, the vehicle which arrives first on the left-lane and decide to go left is referred as "Obstacle Vehicle" and the vehicle arrives later after changing the lane and find another vehicle already occupied the left lane for left-turning movement is defined as "Forthcoming Vehicle". Several reasons are responsible for first left-turning vehicle becomes an 'obstacle' but most important is possibly inattentive driving or intending to disregard the emergence of disturbances and misjudgment of left-leg identification. Obstacle vehicle checks the available headway in current leg for left turning and emergence of disturbance to which it should deal and overcome to go left.

Statistics related to AG3 accident reveals the reason and facts why and how obstacle and forthcoming vehicle were identified for AG3 accident modeling (Table 2). Almost three-fourth of AG3 accident occurs in signalized approach. Over eighty percent AG3 crashes takes place under two-phase signal control as left-turning maneuvering is related to two-phase control. Fifty-eight obstacle vehicles are motorcycle compare to forty-two percent as forthcoming vehicle. Most of the times large vehicles are following vehicle, and obstacle vehicle always suffers severe fatal accident. For turning to the left, most of the obstacle vehicle changes lane abruptly which creates a disturbances for forthcoming vehicle and hence increases the probability of AG3 accident.

Table 2: Arrival of P_f Vehicle Compare to P_o Vehicle Legs

Type of Vehicle	Motor Cycle	Car	Large Vehicle	Changes Lane
Obstacle Vehicle	58%	42%	62%	22%
Forthcoming Vehicle	42%	58%	38%	78%

Formulation of AG3 Accident Risk

A) Formulation for Po: Whether or not a left turning vehicle becomes an obstacle is determined by the judgment of the left turning vehicle driver. The occurrence of judging mistake occurred in left turning traffic flow, including both the judgment of right-side through traffic headway and disturbance occurrence is assumed to be a Poisson process as before-

$$P_o = 1 - e^{-e^{\mathbf{b}_d' \mathbf{x}_d}} \quad (18)$$

where $\boldsymbol{b}_d$ and $\boldsymbol{x}_d$ are vectors of unknown parameters and explanatory variables of disturbance frequency respectively.

B) Formulation for P_f : When P_f vehicle driver intend to disregard the requirement to stop, and continue to move left and stroked by P_o vehicle on the right side of P_o. Similar to the formulation in AG2 accident, it can be assumed that drivers' necessary and available PRTs are Weibull distributed with parameters (á,ì) and (á, γ) respectively, then the probability of the opposite through vehicle driver failed to avoid a collision is

$$P_f = \frac{1}{1 + l/g} = \frac{1}{1 + \exp(-\mathbf{\hat{a}}_{\mathbf{h}}\mathbf{x}_{\mathbf{n}})} \tag{19}$$

where $\boldsymbol{b_h}$ and $\boldsymbol{x_h}$ are vectors of unknown parameters and explanatory variables respectively assuming that λ/γ is nonnegative and follows exponential distribution. Formula (19) is applied to AG3 accident risk evaluation.

If we use P_{AG3} to represent AG3 accident risk of the studying leg, to which the right turning vehicle belong, at certain time period, by combining the formulations of P_o and P_f, the exact formulation of P_{AG3} as follows.

$$P_{AG3} = P_o * P_f = \frac{1 - e^{-e^{\mathbf{\hat{a}}_{\mathbf{d}}\mathbf{x}_{\mathbf{d}}}}}{1 + e^{-\mathbf{\hat{a}}_{\mathbf{h}}\mathbf{x}_{\mathbf{h}}}} \tag{20}$$

3.3 Modeling AG1 Accident Risk

After checking hundreds of original reports of AG1 accident and modeling efforts of Wang *et al* (1998) and Maher (1996), we concluded that the occurrence of AG1 accident is most probably due to the right turning vehicles' invading to the proceeding track of the opposite through vehicles. That is, the obstacle vehicles are normally right turning vehicles and the forthcoming vehicles are generally opposite through vehicles in AG1 accident. There might be various reasons for the right turning vehicles to become obstacles, but the most important ones are the misjudgment of the right-turn vehicle driver and the suddenly emerging of disturbances.

If P_{AG1} to represents AG1 accident risk of the studying leg, to which the right turning vehicle belong, at certain time period, by combining the formulations of P_o and P_f as described in AG2 and AG3 accident, the exact formulation of P_{AG1} is

$$P_{AG1} = P_o P_f = \frac{1 - e^{-e^{\mathbf{\hat{a}}_{\mathbf{d}}\mathbf{x}_{\mathbf{d}}}}}{1 + e^{-\mathbf{\hat{a}}_{\mathbf{h}}\mathbf{x}_{\mathbf{h}}}} \tag{21}$$

4. DATABASE

To enhance the chances of success and to estimate microscopic model, we need the disaggregated data of each of the four approaches of an intersection, such as average daily through, right turn and left turn traffic volumes, all kinds of angle accident number, traffic regulation, geometric and environment related factors and so on. The data are for 190 four-legged, signalized intersections in Tokyo prefecture. This selection was based on intersection size, surrounding land use pattern, and crossing angle. To increase the model efficiency for all kinds of intersection, this study also includes blackspot data (36%). Since the existing accident database could not meet our needs, accident data had to rearranged by checking the original accident records according to registered code. Three years data, from 1992 to 1994, were collected for this study.

Traffic flow data came from manually and the annual site survey reports ("Traffic" 1992-94). Traffic control information, accident collision type and number, and safety improvement data were collected from ITARDA (1991-1995). All applicable angle accidents were cataloged according to their movements before the collisions, and assigned to corresponding approach, to which the involved vehicles belong. For the purpose of this analysis, only collisions involving two-vehicles were examined. Road environment and geometric data were collected from site survey and digital maps (Zenrin, 1996). Research on the effect of driving environment on drivers' behavior found that the increasing complexity (size of functional field of view) decreases and reaction time increases. This means that the increased amount of information for processing significantly lengthens drivers' perception reaction time (Miura, 1992).

5. MODEL ESTIMATION RESULTS

The Negative binomial models were estimated using maximum likelihood method. The log likelihood function evaluated at the estimated parameters, l(â,). In this paper, annual angle accident data were used for the estimation of ANGLE models. Combining Formula (3) and (9a) results

$$P(n_{AG_{ijkl}}) = \frac{\Gamma(n_{AG_{ijkl}} + q)}{\Gamma(n_{AG_{ijkl}} + 1)\Gamma(q)} \left(\frac{q}{f_{jkl} \cdot P_{AG_{ijkl}} + q}\right)^{q} \left(\frac{f_{jkl}\, P_{AG_{ijkl}}}{f_{jkl} \cdot P_{AG_{ijkl}} + q}\right)^{n_{AG_{ijkl}}} \tag{22}$$

Log-likelihood function can be derived straight forward as

$$l(\hat{\mathbf{a}}_{\mathbf{h}}, \hat{\mathbf{a}}_{\mathbf{d}}, q) = \sum_{j=1}^{3} \sum_{k=1}^{190} \sum_{l=1}^{4} \ln\left(\frac{\Gamma(n_{AG_{ijkl}} + q)}{\Gamma(n_{AG_{ijkl}} + 1)\Gamma(q)} \left(\frac{q}{f_{jkl} \cdot P_{AG_{ijkl}} + q}\right)^{q} \left(\frac{f_{jkl} \cdot P_{AG_{ijkl}}}{f_{jkl} \cdot P_{AG_{ijkl}} + q}\right)^{n_{AG_{ijkl}}}\right) \tag{23}$$

where $\boldsymbol{b_d}$ and $\boldsymbol{b_h}$ are vectors of unknown parameters of the probability of encountering obstacle vehicle (P_o) and the probability of the forthcoming driver's failure to avoid the collision (P_f) respectively. If *á* is significantly different from zero, then the Negative Binomial is the correct approach. In this study, all the models are estimated by negative binomial regression. Models are independent from each other. The same symbols, such as θ, have different values in different angle accident models.

Table 3: Estimation Results for Accident Risk Models

Other parameters in the model	AG1 Model	AG2 Model	AG3 Model
Reciprocal of Negative binomial Dispersion Parameter (è=1/á)	0.836 (9.38)	0.708 (4.58)	2.154 (3.85)
Average Probability of Encountering an obstacle vehicle (P_0)	0.133 (1.47)	0.159 (1.64)	0.295 (2.15)
Average Probability of the Failure of adjacent Right or left Through Vehicle Driver (P_f)	$1.28*10^{-6}$ (1.55)	$5.25*10^{-6}$ (3.50)	$3.8*10^{-6}$ (4.47)

Table 3 shows the basic estimation results for negative binomial models. The value of reciprocal of Negative Binomial dispersion parameter implies that use of negative binomial model is justified by the highly significant value of p= 0.15. Use of Poisson regression would have produced considerable bias in coefficient estimates. Average probability of encountering an obstacle vehicle (P_0) is much higher than the average probability of following vehicle driver (P_f), which is quite reasonable because it's often interrupted by disturbances, but accident rate is vary rare as human beings have little failure probability in dealing with the interruptions.

Results of Angle Accident Modeling

According definition of AG2, AG3 and AG1 accident is accredited to through traffic flow, left-turn flow and opposite leg through flow respectively, for the development of angle accident modeling all these flows are considered for estimation purpose. Estimation results are shown in Table in 4, 5 and 6.

Table 4: Estimation Results of Factors Affecting P_0 and P_f for AG2 Model

Parameters for P_0 Vehicle (β_d)	Co-efficient	Parameters for P_f Vehicle (β_h)	Co-efficient
Constant	-1.924 (-3.04)	Constant	-15.57 (-30.64)
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 (1.44)	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 (-1.57)
Right-turn restriction (1 if right–turns is restricted, 0 otherwise)	1.101 (1.21)	Existence of driveway (1, if driveway exist, 0 otherwise)	0.138 (1.6)
Curvature on approach leg(1 if curve on approach, 0 otherwise)	0.207 (1.65)	Angle of entering approach and opposing approach (1 if larger than 15, 0 otherwise)	-0.591 (-1.56)
Angle road in between two adjacent legs(1 if two adjacent legs contain an angle road in between them, 0 otherwise)	1.977 (4.99)	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)
Disturbing structural element on the leg of interest (1 if disturbing structural element exist, 0 otherwise)	0.169 (1.51)	Local street approach (1 if local street approach, 0 otherwise)	0.881 (2.95)
Sight-distance restriction (1 if sight distance is restricted, 0 otherwise)	0.964 (2.91)	Permissive right turn (1 if permissive right turn, 0 otherwise)	-2.12 (-5.95)
Intersection sheltered by elevated road (1 if one direction is under an elevated road, 0 if no elevated roads above)	1.81 (3.98)	Protective/ permissive right turn (1 if protective or permissive, 0 otherwise)	-0.682 (-1.67)
No control on current leg (1 if no control, 0 otherwise)	-1.352 (-2.68)	Large vehicle ratio of current leg	0.053 (2.80)
Pedestrian overpass at the corner current leg (1 if pedestrian overpass exist, 0 otherwise)	0.317 (1.57)	Right or left-turn restriction (1 if right or left-turns are restricted, 0 otherwise)	0.948 (1.78)
Central road median (1 if wider than 2 meters, 0 otherwise)	0.524 (1.24)	Exclusive right lane (1 if there exist exclusive right lane, 0 otherwise)	-0.342 (-1.31)
Right approach road width (in meter)	-0.048 (-1.97)	**Sample Number**	745 of 760
Right-turn volume in thousands (3 years) of the current approach	-0.077 (-1.18)	**Log likelihood at convergence, l(è)**	505.451
Through traffic volume in thousands (3 years) of the right approach	0.075 (2.31)	**Log likelihood with constants only, l(0)**	953.85
Through traffic volume in thousands (3 years) of the left approach	0.076 (2.52)	**Likelihood ratio Index**	0.41
Total traffic volume in thousands (3 years) of the opposite approach	-0.059 (-4.66)		

Traffic Regulation Related Variables and Findings:

Existence of Exclusive Right Lane on approaching road is significant for AG1 and AG2 accidents. The presence of EXCLRT reduces angle accident chances due to smooth maneuvering of right-turning vehicle, which reduces the probability of conflict at approach of intersection and significant amount of approaching vehicle swings smoothly to right lane reducing the probability of AG2 accident (Datta K., 1991). No-control approaches usually signify low cross-street volumes, exceptionally good sight distances, and other sometimes unobserved factors that lead to a tendency toward low overall accident rates (which is often why no control is warranted).

As right turning maneuvering takes significant time, through vehicle in AG2 accident approaching at intersection from combine through and right lane have slowed down for right-turn and consequently following vehicle already visualize the obstacle vehicle location and hence tends to pass it away. The variable indicating protective right turn has a coefficient that shows that if the approach has protected right turn, then AG2 accidents tends to decrease. If there are more right-turn lanes, the existence of the right-turning vehicles may be difficult to be found by opposite through vehicle drivers, thus the average APRT should be shorter as well (Wang Y., 1998).

Table 5: Estimation Results of Factors Affecting P_0 and P_f for AG3 Model

Parameters for P_0 Vehicle (β_d)	Co-efficient	Parameters for Pf Vehicle (β_h)	Co-efficient
Constant	-3.745 (-6.22)	Constant	-20.17 (-23.49)
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 otherwise)	-1.49 (-3.74)	Intersection sheltered by elevated road (1 if one direction is under an elevated road, 0 if no elevated roads above)	-0.29 (-1.35)
Intersection Location (1 if in central business district, 0 otherwise)	0.32 (1.85)	Total lane number of entering approach	0.42 (3.82)
Fence (1 if exist, 0 otherwise)	-0.42 (-1.56)	Large vehicle ratio of entering approach	-0.03 (-1.70)
Two Phase signal (1 if exist, 0 otherwise)	0.549 (1.41)	Slope of the entering approach (0 if within ±3%, 1 otherwise)	0.30 (1.43)
Number of driveway on the left of the approach	0.63 (1.83)	Number of through lane of left approach	0.11 (1.88)
Total lane number of left approach (including both entering lanes and existing lanes)	0.11 (3.45)	Speed Limit of the entering approach	0.01 (1.25)
Local street approach (1 if local street approach, 0 otherwise)	-2.09 (-2.14)	Angle of entering approach and left approach (1 if less than 105 degree, 0otherwise)	0.18 (1.88)
Sight-obstruction (1 if sight distance is restricted, 0 otherwise)	1.18 (3.42)	**Sample Number**	745 of 760
Through traffic volume in thousands (3 years) of the Right turning approach	0.03 (1.29)	**Log likelihood at convergence, *l*(è)**	505.451
Ratio of Motor cycle volume (3 years)	1.07 (1.54)	**Log likelihood with constants only, *l*(0)**	953.85
Through traffic volume in thousands (3 years) of the entering approach	0.01 (4.40)	**Likelihood ratio Index**	0.47
Right-turn volume in thousands (3 years) of the opposite approach	-0.003 (-1.41)		

Geometry Approach Variables and Findings:

Angle road between to adjacent legs creates disturbances at the corner point of two legs, causing impediment for obstacle vehicle that ultimately ended up with AG2 accident. Approach half-width of the right-hand arm is significant for right angle accidents and indicated that the wider the approaches are associated with lower accident frequency of this type (Hall R.D., 1986). Sight distance restriction would be realized when the standard sight line based on the speed of traffic on the cross street is not provided from the stop point on the approach to cross traffic in both directions. A sight-distance restriction also occurs at a signalized approach due to horizontal or vertical curvature across the intersection, an object in a median area, or misaligned right-turn lanes.

Existence of driveway near intersection approach always create disturbance which affects positively for following vehicle driver for AG2 accident and obstacle vehicle driver for AG3 accident. Specially for AG3 sudden emergence of vehicle from driveway near intersection leads left lane vehicle driver to sudden stops and makes obstacle for Pf vehicle driving. Total lane number is considered to be proportional to drivers' sight field. The wider (more lanes) the approach is, the better the drivers' sight condition (Wang Y., 1998).

Table 6: Estimation Results of Factors Affecting P_0 and P_f for AG1 Model

Parameters for P_O Vehicle (β_d)	Co-efficient	Parameters for P_F Vehicle (β_h)	Co-efficient
Constant	-3.13 (-4.75)	Constant	-12.68 (-13.96)
Angle road in between two adjacent legs (1 if two adjacent legs contain an angle road in between them, 0 otherwise)	-0.112 (-1.55)	Current leg Speed Limit	0.026 (2.63)
Exclusive Right Lane (1 if Exclusive right exist, 0 otherwise)	-0.274 (-1.59)	Opposite Leg left-turn traffic volume	0.009 (1.49)
Disturbing structural element on the leg of interest (1 if disturbing structural element exist, 0 otherwise)	0.179 (1.25)	Functional field of view (1 if angle of clear view is greater than 10 degree, 0 otherwise)	-0.812 (-4.71)
Sight-distance restriction (1 if sight distance is restricted, 0 otherwise)	0.126 (1.55)	Large vehicle ratio of the entering approach	0.02 (1.49)
Angle of entering approach and right approach (0 if within 75° and 105°, 1 otherwise)	0.059 (1.41)	Total entering lane number of the opposite approach	-0.268 (-3.63)
Sight-distance restriction (1 if sight distance is restricted, 0 otherwise)	1.091 (5.80)	Motorcycle ratio of opposite through traffic	1.686 (1.26)
Signal control pattern (1 for 2 phase control, 0 otherwise)	-0.368 (-1.47)	Angle of the entering approach and opposite approach (0 if within –30° and 30°, 1 otherwise)	0.507 (1.10)
Curvature on approach leg(1 if curve on approach, 0 otherwise)	-0.438 (01.31)	The existence of more right-turn lanes (1 if more than 2 right turn lanes, 0 otherwise)	0.43 (1.72)
3 years' daily average right-turn traffic volume in thousands of the entering approach	0.014 (1.43)	**Sample Number**	746 of 760
Local street approach (1 if local street approach, 0 otherwise)	0.904 (3.24)	**Log likelihood at convergence, *l*(è)**	1129.92
Road median (0 if none, 2 if wider than 2 meters, and 1 otherwise)	1.091 (4.29)	**Log likelihood with constants only, *l*(0)**	2305.95
Absolute Displacement between two opposite legs (1 if displacement exist, otherwise)	0.973 (5.88)	**Likelihood ratio Index**	0.51

Wider median aggravate the sight angle for the drivers and eventually produce conflict for an obstacle vehicle to end up with an AG2 collision. In intersections, a wider median means a longer travel distance for right turn vehicles and more difficult choose conflict chance with opposite through vehicles. This conjecture is further proved by AG1 accident estimation. In intersection local streets are situated just adjacent to national highway or prefectural roads and AG2 accident happened one vehicle coming from major street and another from local Street and hence parameter sign is positive in the model having comparatively higher number of accident.

Functional field of view (Miura T., 1992)". in this study is adopted depending on number of disturbances and angle of clear view from 30m away from the starting of approach road edge at intersection. Coefficient indicates that if FOV is 1, AG2 accident frequencies reduces (22 accidents). Absence of narrower vision or turmoil enables driver to detect the obstacle vehicle easily and consequently reduces the probability of AG2 accident occurrence.

Other Geometric Variables and Findings:

If an elevated road shelters an intersection, the darkness will surely delay the perception of through vehicles in the intersection and hence increases the likelihood of this type of accident frequency. The finding that intersections located in central business district (CBD) have lower P_o is a little different from our imagination. Poch *et al* (1996) and Wang *et al* (1998) got the same results when analyzing intersection rear end accident frequency using negative binomial regression. The variable displacements of the centerline of the arm indicates displacement to the left to be safer than displacement to the right for such accidents. Increased displacement of the left hand arm with respect to the right hand arm does associated with higher AG1 accident frequency

Angle of the entering approach and through approach contain more complex information than regular-shaped intersections, and the increased complexity should have increased NPRT. If, however, consider the existing angle may seriously reduce through vehicle speed, and hence increases APRT, the decreasing effect on AG1 accident risk may be also acceptable.

6. SUMMARY AND CONCLUSIONS

We have used accident data and information about intersection to build models for the estimation of angle accident risk at signalized intersections. Compare to previous studies, this study focus on the evaluation of accident risk rather than accident number which determines the effects of accident risk due to change in countermeasure. If the effect of explanatory factors intersection risk is obtained, we might be able to find some efficient measures to improve intersection traffic safety.

During the course of model development we reached some useful insights. First, to portray the microscopic view of intersection accident, we developed the concept of mechanism of angle accident occurrence based the movements of obstacle and following vehicles driver behavior when they approach to intersection. Accident risk is the product of the probability of encountering an obstacle (P_o) and the probability of forthcoming vehicle driver failed to response effectively (P_f). Second, it appears that the customary categorization of accidents is effective information for safety management controls. Third, a close examination of accident risk and explanatory variables reveals that effect of traffic flows on angle accident does not seem to strongly depend at all on larger of the traffic flows.

Empirical link functions were adopted to relate factors affecting leading vehicles' deceleration and following drivers' response to P_o and P_f respectively. A negative binomial model for assessing the angle accident was developed and successfully estimated by using MLE. Using these models others types of intersection accident can be modeled as well. Besides, further works for exploring the different forms of P_o and P_f for various types of intersection accident should also be put in action as to understand the effects of various controllable factors on the safety improvement at intersections.

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