Gap Acceptance Behavior Model for Non-Signalized T-Intersections on Malaysia Rural Roadway

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Abstract - The paper proposes field studies that were performed to determine the critical gap on the multiple rural roadways Malaysia, at non-signalized T-intersection by using The Raff and Logic Method. Critical gap between passenger car and motorcycle have been determined.   There are quite number of studied doing gap acceptance behavior model for passenger car however still few research on gap acceptance behavior model for motorcycle. Thus in this paper, logistic regression models were developed to predict the probability of accepting or rejecting a given gap for right turn rider from minor road considering a number of potential influence factors. Gap sizes, waiting time, speed, lane change and type of on-coming vehicles were found to be significant.

Keyword: Critical gap, gap acceptances behavior, logistic regression

1. Introduction

According to (Malaysia Royal Police, 2008), Rural Route 50 was experience about 1,784 accident at the junction for over 4 year period from year 2003 to 2007 second higher behind driving to close stated 2,759 cases. This phenomenon could explain the risk of distance and gap length for turning vehicles from junction to enter the main stream. Numerous studies have examined driver behavior at non-signalized intersection and their respond to different gap in priority stream. Gap acceptance may be used to predict the relative risk at intersections, where shorter gaps usually involve higher accident risk [1].

Previous research carried out by [2] the probability that a driver will have an accident or near miss when turning right across a stream of traffic are depend on size of the gap that a driver will accept in an oncoming stream, velocity, age, sex and type of on-coming vehicles. Gap is defined as the time elapsed between the rear bumper of one vehicle and the front bumper of the following vehicle in the traffic stream of major road at a reference line. Gap acceptance decision involve making a judgment about whether it is possible to complete a maneuver before an oncoming vehicles arrives [3]. Critical gap has been defined for instance as "the minimum time gap in the priority stream that a minor street driver is ready to accept for crossing or entering the major stream conflict zone [4].

Another definition given by [5] defines the critical gap as the gap for which the percentage of traffic that will accept a shorter gap is equal to the percentage of traffic that will reject a longer gap. [6] compared the prediction capabilities of neural network and binary-logit models in predicting driver's tendency either to accept or reject the gap at rural roadway. The authors found that the driver decision to accept to accept or reject a gap can be inclined by the following factor: type of control at the intersection, the turning movements in both major and minor road, size gap, vehicle speed and waiting time in minor road.

Previous study proposed [7] used logit model modeling technique for developing gap-acceptance functions. [8] also used logit models to model gap acceptance in a study of intersection sign distance on the basis of gap acceptance. They are four types of maneuver at non-signalized intersection: a right turn from minor road, a right turn from major road, a left turn from minor road and a left turn on the major road. [9], when surveying motorcyclist perceived likelihood of being involved in accident also found that repeated speeding and changing between lanes of traffic were the main factors of fatal crashes.

According to a data analysis carried out by [10], lane change or merge accident occur under "normal" driving condition, that is daylight and clear weather. The common scenario in these types of crashes is that the driver who is unaware of the other vehicle when he or she performs a lane change fails to respond with a recovery maneuver to avoid the crash. [10] identified eight classification of lane change/merge crashes. They include: angle striking, angle struck, drifting, rear-end struck, leaving a parking place, both changing lanes, sideswipe and rear-end striking. Previous studied that has been done [11] found that right turn motorcycle onto main stream from the minor road has significant effect on the accident.

There are quite number of studied doing gap acceptance behavior model for car passenger [12]

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however still few research on gap acceptance behavior model for motorcycle. In this paper, binary logit models were developed to predict the probability of accepting or rejecting a given gap for right turn vehicle from minor road non-signalized T-Intersection considering a number of potential influence factors. Gap sizes, wait time, speed, lane change and type of on-coming vehicles were found to be significant.

2. Logistic Model

Driver has two options either to accept or reject the gap to cross onto the intersection. Logistic regression has been broadly used in the research to model these types of discrete choice behavior and is suitable method for this study. The driver's decision may depend on, length of the gap provided, the speed of the oncoming vehicle, vehicle maneuver and wait time at the intersection. All the decision for right turn driver called the utility of the decision. The functional form can be represented as follows:

$$U_i = V_i + \varepsilon_i \tag{1}$$

where U_i = the tendency of a randomly selected motorist to accept gap i or total utility. V_i = observed utility and ε_i = a random error component or utility error. V_i, observed utility, is a function of difference variable component that of the randomly selected driver's tendency to accept gap i is expressed as:

$$V_i = b_0 + b_1 X_{1i} + b_2 X_{2i} + \ldots + b_n X_{ni} + \varepsilon_i \tag{2}$$

where b_0=constant, b_1, b_2 and b_n= is the regression coefficients, X_1- X_n= other explanatory variables.

The probability at a randomly selected driver will accept gap,(P_{Rturn}) is given by the logistic function:

$$P_{Rturn}(i) = \frac{1}{1 + e^{-(Vi)}} \tag{3}$$

The critical gap is that gap for which the probability of accepting is 0.5 [13]. The logistic function can be transformed into a linear equation:

$$P_{Rturn}(i) = \ln\left(\frac{p}{1-p}\right) = b_0 + b_i X_{1i} \tag{4}$$

where P_{Rturn} = right turn vehicle. The critical gap is the x-value, obtained by substituting P with 0.5.

Data were collected at two separated non-signalized T-intersection rural roadway in the Batu Pahat area of Malaysia. The selection of this intersection in the study base of the several similarity such as the turning angel, controlled by stop sign on the minor road and no control on the major roadway. The major road at each intersection was a four lane two-way highway that runs 47 kilometer length. Both intersections located at the section were identified as hazardous area in Section 10

and Section 9 non-signalized intersection. Figure 1 shown the number of accident at both section, whereas section 10 stated 18 fatal cases meanwhile section 9 recorded 7 deaths case over 5 years accident data (2006:2010) from (Malaysia Royal Police, 2011). The data were collected in September 2010 on typical traffic days.
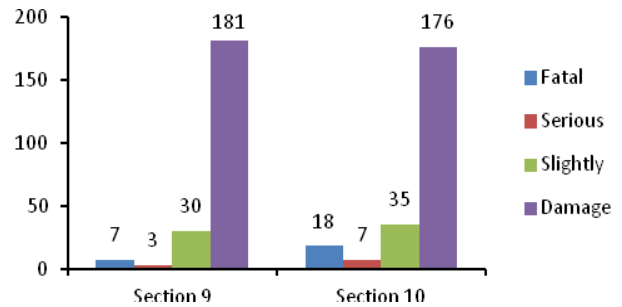

Figure 1: Number of accident according its type at study location (2006-2010).

3. Data Collection

The purpose of the field studies were to obtain or collect the following data: Right turn vehicle; duration times of gaps in major road that are accepted and rejected by the minor road vehicles; the velocity use by the major road traffic to allow the turning right vehicles; type of vehicles making right turn from minor road; types of pair (First and Second) vehicles in the traffic stream is accepted by the minor road driver; wait time; and lane change. Type of pair vehicle can be described as first and second type of vehicle in the major road is accepted by the right turn driver. First and second type of vehicle on the main stream include in the dependent variable model are passenger car, motorcycle, lorry and bus.

According to [14], a lane change defined as a deliberate and substantial shift in lateral position of a vehicle with intention of traversing from one lane to an adjacent lane. This maneuvers class includes a simple lane change, merge, exit, pass and weave. Driver lane changing behavior has direct influence on the capacity and safety of such area [15]. In this study change lane defines as vehicles changing lanes at the intersection due to right turn vehicle in the minor road. From video camera analysis traffic vehicle on the main stream was forced to change lane across the highway to avoid a right turn vehicle on the minor road. The probability of lane change crash occurs when the driver attempts to change lanes and strikes or is struck by a vehicle in the adjacent lane.

Waiting time is defined as the times allocate by the driver at the in front of queue before decide to accept a gap and turn right into the intersection. Figure 2, illustrates typical data traffic collection arrangement for the site studies. Video camera was setup at the best angel in order to record the traffic behavior vehicle right turn from minor road and the behavior of successive vehicles on the major road. A total three hour video camera has been collected, from 13:00-14:00 and 16:00-18:00 for Section 9 and Section 10 intersections respectively. In

summary, a total 479 acceptance/rejection decision were evaluated by right turn drivers, resulting in 203 acceptances and 276 rejections. Of these 203 minor road vehicles, 103 right turn decision by motorcycle and 100 right-turn decision by passenger cars. For critical gap analysis only motorcycle and passenger cars were selected meanwhile the development of gap acceptance behavior model simply focus on the motorcycles.

3.1 Event at Multi-lane Junction

The geometrics junction is illustrated in Figure 2. The main road facility consists of a four-lane two-way undivided carriageway with a two lane minor road street. The driver could expose conflicting maneuvers scattered on each traffic road lanes with the minor road drivers. In this paper they are four type of gap event that has be identify for gap acceptance analysis included conflict potential with minor street right-turn vehicles. Figure 5 illustrated four type gap events. A gap event 1 defines as the pair vehicle in the lane 1 or 2 is accepted by the minor road driver. Pair vehicle consisted first vehicle passing the head of queue vehicle in the minor road, meanwhile second vehicle allowed the right turn driver into main stream. Second vehicle in lane 1 have potential conflict with the right-turn vehicles. Second gap event, defines as the pair of vehicle in lane 3 is accepted by the right-turn minor road driver. The potential conflict normally occurs when the second vehicle accommodated the right turn vehicle. Third gap events defines as the gap accepted between first vehicle in the lane 1 or 2 passing the head of vehicle queue in the minor road and following the second vehicle in lane 3 allowed the right-turn vehicle.
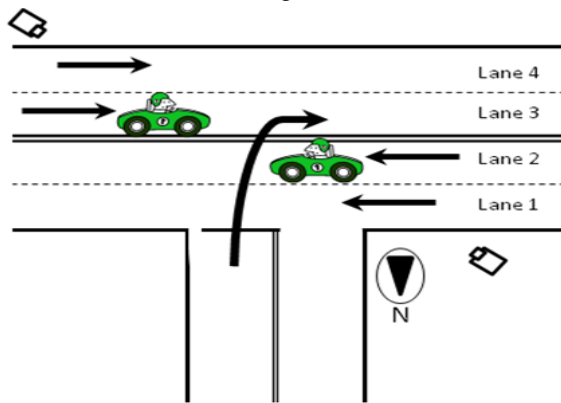

Figure 2: Type of gap events at the multiple-lane intersections.

Have probability conflict happed for the second vehicle in lane 3. Lastly fourth gap events defines as the gap accepted between first vehicle in lane 3 passing the head of queue vehicle in the minor road and the second vehicle in lane 1 or 2 allowed the right turn driver. The conflict potential occurred for the second vehicle in the lane 3.

3.2 Critical Gap

More than sixty year ago, [15] introduced a macroscopic model for estimating the critical gap. His defined the critical gap as the value of t where, the

functions $1-Fr(t)$ and $Fa(t)$ intercept. The value of tc at which;

$$Fa(t) = 1 - Fr(t) \qquad (5)$$

The simplicity of this method to be the reason many countries has prefer to used and it is still being implement in some research project today. The Raff Method and the Logit Method, also recognize as Logistic Regression, [16]. Previous research [17] stated both the Raff and Logit methods are biased. However [18] proved that the biased is likely to be small.

Figures 3 and 4 show the application of Raff Method to the data for both accepted and rejected gaps in right-turning maneuvers. In this data analysis only right-turn maneuver in which there was no disturbance from other vehicles with the gap acceptance or rejection decision are considered in the graph. The Raff Method involved determination of the cumulative distribution of rejected gaps and the match of cumulative distribution of accepted gaps. While the critical gap is obtained at the point intersects between rejection curve and accepted curve. In this study, the critical gap for motorcycles and Passenger cars were 4.8 sec and 5.5 seconds respectively.
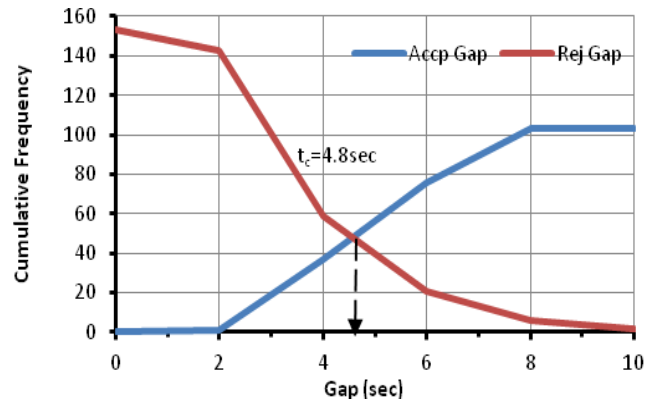

Figure 3: Cumulative distributions of accepted and rejected gaps in right-turn maneuvers by motorcycles
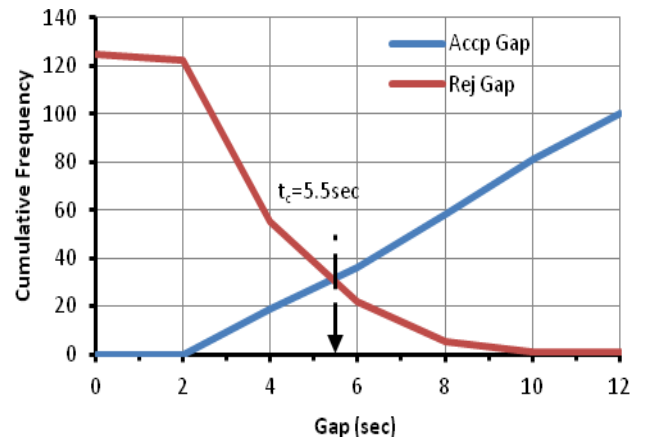

Figure 4: Cumulative distributions of accepted and rejected gaps in right-turn maneuvers by passenger cars
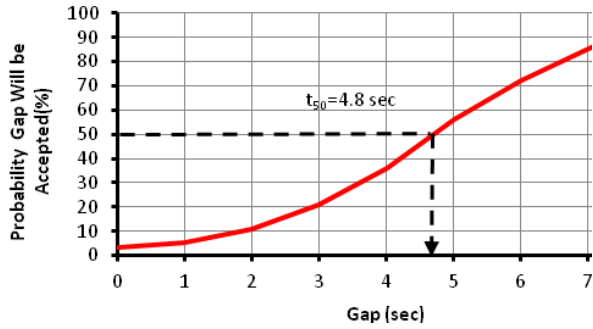
Figure 5: Probability of acceptance gaps in right turn maneuvers by motorcycles.
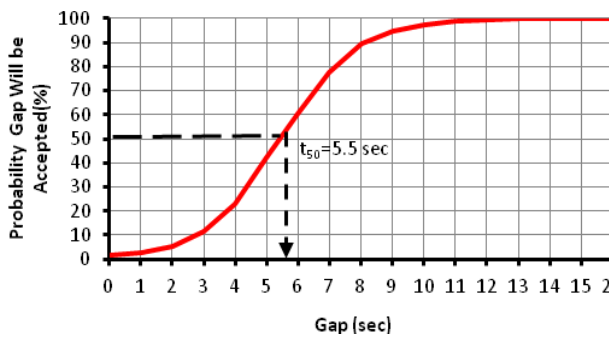

Figure 6: Probability of acceptance gaps in right turn maneuvers by passenger cars

Logistic regression is a statistical approach for developing predictive models for probability that an event (example gap acceptance) be able or not able to occur. As logistic regression is applied to the same dataset shown in figure 5 and 6, the following predictive equations for motorcycle and cars passenger are established;

$$P_{Motorcycle} = \ln\left(\frac{p}{1-p}\right) = -3.599 + 0.756x \qquad (6)$$

$$P_{Passanger\ Car} = \ln\left(\frac{p}{1-p}\right) = -4.650 + 0.865x \qquad (7)$$

The estimation results of critical gap analysis by using logistic regression model at both intersections are shown in Table 1.

Table 1: Result of parameter estimation of critical gap

Variable	Motorcycle Estimate	T-Stat	Pass. Cars Estimate	T-Stat
Constant	-3.599	69.27*	-4.650	63.69*
Gap	0.756	68.66*	0.865	60.59*
Sample	258		221	
R^2	0.56		0.70	
H.R	81.0%		84.6%	

*=Significant at the 99% level, respectively, *H.R= Hitting Ratio*

The value of t critical can be obtained by substituting *P* =0.5 in equation 2 or 3 to work out the value of *X*. Equation 2 and 3 demonstrate by the graph in figure 5 and 6. The result of critical gap by using Raff method and Logistic Regression Method   involved two categorize vehicle shows the critical gap for motorcycle was shorter than passenger cars.

4. Gap Acceptance Behavior Model

As mentioned earlier, the data collection effort resulted in a total of 258 observations. 103 right turn motorcycle (RTM) was presented. To understand the effect of various factors on the gap acceptance behavior of the drivers, logistic regression models were developed to fit the data. A stepwise selection method was used to identify the significant variable. The Logistic Regression Method in SPSS was used to develop the models. A stepwise selection method was used to determine the significance level used was 0.05. Table 2, defines the attributes used in the developing the gap acceptance model.

Table 2: Description of the study variable

Variable	Description
WT	Waiting Time (second)
Gap	Gap which is rejected or accepted (second)
Speed	Approaching speed of the second vehicle that allows the RTM into the mainstream (per km)
LC	Lane change occurred (LC: 1, otherwise: 0)
SPC	SPC =1, if the second vehicle passing the RTM is passenger car and 0 otherwise.
SMc	SMc =1, if the second vehicle passing the RTM is motorcycle and 0 otherwise.
FPC	FPC =1, if the first vehicle passing the RTM is passenger car and 0 otherwise.
FMc	FMc =1, if the first vehicle passing the RTM is passenger car and 0 otherwise.

Table 3: Result of RTM parameter estimation

Variable	Estimate	t-Statistic
Constant	-5.816	-59.58**
Waiting Time(WT)	0.039	8.38***
Gap	0.784	56.88***
Changing Lanes (CL)	2.098	2.93*
Second Passenger Car (SPC)	1.846	14.08***
Second Mc (SMc)	2.514	10.13**
Sample	257	
R^2	0.56	
Hitting Ratio	81%	

*,**,***=Significant at the 90%,95% and 99% level, respectively

The result of the parameter estimation is shown in Table 3, represent that both R^2 and hitting ratio are adequate enough with R^2 0.55 and 81% respectively. The gap acceptance behavior shows the waiting time significantly influences the probability of accepting gap. The positive sign indicate that as rider at head of queue likely to accept the shorter gaps as the waiting time at the head of queues increase. Gap acceptances represent the highest t-Statistic

with 56.88. The changing lanes from the major road appear to be significance at 5% confident level. The positive sign of changing lane show, the driver is likely to accept shorter gaps. Furthermore second passenger car and motorcycle in the traffic stream is accepted by the minor road rider was found significance with t-Statistic 14.08 and 10.13 respectively. The positive sign indicate the rider likely to enter the traffic stream with shorter gap.

5. Summary

Base on the Table 4, the motorcycles and passenger cars turning right are not comply either Malaysia Standard (ATJ 11/87) nor (U.S.HCM 2000). By using Raff Method critical gap for motorcycle were shorter than car passenger with 4.8 seconds and 5.5 seconds respectively. Gap acceptance model in this study found that the effected of gaps size on the time taken to cross the intersection are supported with previous research [19]. This paper made an effort to model gap acceptance behavior of riders using various traffic characteristic of a site. Gap acceptance model at non-signalized T-intersection controlled by stop sign at rural roadway has been developed and estimated to find the main factors that influence riders making right turn onto intersection. Driver decision to either accept or reject a gap was modeled using logistic regression models. The result reveal variables that significantly affected right turn maneuver are waiting time, gap size, lane change, passenger car and motorcycle. The increasing of waiting time would influence driver to accepted shorter gaps length. Meanwhile other factor like characteristic of oncoming vehicle (speed, changing lanes, passenger cars and motorcycle) would forcing the rider to accept the shorter gaps or it can also call the critical situation for the right turning rider across on-coming traffic.

Table 4: Comparison of the critical gap values

Right Turning Vehicle from Minor Road (sec)		
Method	Car Passenger	Motorcycle
Raff-Method	5.50	4.80
Logistic Regression	5.37	4.76
Malaysia Standard	7	
U.S HCM 2000	7.5	

The shorter the gap acceptance the higher the conflict may occur and potential of accident would be happen. This result shows that motorcycles can be classify as among dangerous vehicle crossing the major road comparing with car passengers.

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