

An Analysis of Right-Turning Vehicles and Gap Acceptance Behaviour Models on Malaysian Rural Roads

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ABSTRACT

Road accidents are regarded as a leading cause of both human and financial losses in countries at all stages of development. In Malaysia, 548,598 accidents occurred in the year 2018 alone. This resulted in an average of 16 people killed every day due to traffic accidents. The key objective of this study is to recognize the causal factors such as dangerously moving vehicles that largely contribute to the occurrence of traffic accidents, critical injuries and deaths at points of access or in this case, the unsignalised intersection. The study focused on right-turning vehicles (RTVs) demonstrating gap acceptance and conflict analysis at three unsignalised intersections along Federal Route 50 (Ft 50). The selected intersections were located in Road Sections (RS) 10, 9, and 2. Logistic regression was used to develop analysis models of gap acceptance behaviour. In analysing gap acceptance, five gap patterns were suggested to incorporate each potential gap pattern displayed by RTVs in a range between large and small roads at a T-junction. The study findings were used to thoroughly examine how drivers behave with regard to gap acceptance and serious conflicts, utilizing the suggested gap patterns displayed by RTVs. The paper demonstrated how second vehicle variables influenced the acceptance of shorter gaps by RTVs. Such variables included serious nose-tail and angular conflicts, and also when motorbikes or passenger cars were the vehicles going past the RTVs. Meanwhile, a longer gap was accepted by RTVs encountering traffic lights and channelization. From the investigations conducted as part of the study, the main proposal is for average gap pattern 3 at unsignalised intersection to form the basis for developing feasible countermeasures for road accidents.

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1. Introduction

According to the Global Status Report WHO (2018), the number of road traffic fatalities had increased to 1.35 million in 2016. Motorcyclists, cyclists and pedestrians were identified as vulnerable road users representing more than half of all global road fatalities. Motorcycles and passenger cars were involved in 28% and 29% of all fatal crashes respectively. Both motorized vehicles (motorcycles and passenger cars) also contributed 43% to all road fatalities in South-East Asia. Based on statistics from the Royal Malaysia Police RMP (2020), in 2019, Malaysia recorded 567,516 road crash cases whereby 6,167 cases involved fatality. From the total number of road crashes, motorcycles recorded the highest number with 76.9% followed by passenger cars at 13.5%.

Road accidents are regarded as a significant cause of both human and financial losses. In Malaysia, road traffic accidents have been increasing in number, especially on rural federal roadways. For example, on Federal Route 50 (Ft 50), traffic accidents have rapidly increased by 10 times in the last 10 years. For rural federal roads, the population along the roads and the traffic volume are increasing rapidly. At the same time, there are many unsignalised T-junctions (hereafter referred to as access points) and high-speed vehicles. An access point is a unsignalised 3-leg intersection connecting minor roads to major roads.

Various studies of Malaysian roads have concluded that a major factor contributing to crash fatalities and serious injuries is these access points. In a one-hour observation period, numerous serious conflicts and dangerously moving vehicles were noted; these

resembling the situations leading to traffic accidents (Fajaruddin, 2013).

Radin et al. (2001) reported on the significant number of research involving analyses of road safety particularly involving accident rates (the frequency of accidents). The Safety Research Center at University Putra Malaysia analysed the accident factors using GLM models. The Centre found that traffic volume on major roads, lane width, and access points are relevant to the accident rates. Harnen et al. (2003) developed a motorcycle crash prediction model based on Malaysian urban roads. The researchers discovered that crashes involving motorbikes were significantly affected by traffic flow (straight lines), vehicle speed, lane width, and land use. Nevertheless, their research was conducted in urban areas where the road circumstances were different. Moreover, serious or fatal accidents, dangerous vehicle movements and the volume of traffic entering and exiting minor and major roadways were not considered in the study.

Donaldson et al. (2006) analyzed the fatality risk from crash records of motor vehicles in Utah, the United States. They found that the risk was higher on rural roads compared to urban roads. Wedagama and Dissanayake (2010) investigated fatal accident factors in Bali. The study indicated that the probability of fatal accidents for female drivers was higher than male drivers; and the study only concentrated on accident factors involving the gender and age of the driver.

On the other hand, Hagiwara et al. (2010) studied various factors of fatal and injury-related accidents using long-term accident data in Japan. The researchers indicated that driving mileage per age was more desirable as an exposure value. Patwary et al. (2010) analyzed many influential factors affecting injury severity and collision type of traffic accidents using a Japanese accident database which was composed of signalized four-leg intersections. The researchers analyzed the accident factors in Japan. Fajaruddin & Fujita (2011) carried out a study of accident prediction model using multiple regression. It was noted that the factors which contributed to accidents on four-lane two-way undivided rural roadways were the number of access points, vehicle speed, Annual Average Daily Traffic (AADT), number of motorcycles and motorcars and gap vehicles.

Mahmassani and Sheffi (1981) developed a probit model to analyse the gap behaviour of left-turning passenger cars at an unsignalized intersection. Additional works can be found such as by Devarasetty et al. (2012) and Harwood et al. (1999) which used logistic regression to model gap acceptance for left-turning passenger cars from major roads at unsignalized intersections. On the other hand, Gattis and Low (1999) developed a logit gap model and found that drivers who were involved in conflicts were too comfortable with short gaps.

An alternative approach is necessary to analyse the probability of accident at intersections. However, not all accident data can be obtained. Thus, traffic conflicts were preferred to overcome this issue. Caliendo et al. (2012) proposed a microsimulation technique to generate traffic conflicts at three legged and four legged unsignalized intersections using AIMSUN simulation software with SSAM software. Time to Collision (TTC) and Post-Encroachment Time (PET) were applied to identify critical conflicts. The researchers found that the value of TTC and PET was within the range of 0 to 1.5 seconds and 0 to 5 seconds respectively. Furthermore, it was concluded that both traffic conflict methods could be implemented as the latest approach to estimate crash at unsignalized intersections.

Using regression models, Fajaruddin (2013) analyzed the fatal and serious accident factors from many aspects. The results showed that the movement of a right-turning motorcycle from a minor road can be classified as the most dangerous movement. Thus, this study aims to carry out a more in-depth analysis of the behaviours on gap acceptance using our proposed 5 gap patterns to consider all the possible gap patterns for right-turning vehicles (both motorcycles and passenger cars) from the minor road at an unsignalized T-junction. Gap acceptance models are developed to identify factors contributing to fatal-serious conflicts at the access points in the study (unsignalized T-junction). Based on the findings, various countermeasures to reduce the probable road accidents shall also be discussed.

2. Data Collection

The Royal Malaysia Police records the road accident data on a standard form called POL27. Each record is subsequently copied and updated on MIROS (Malaysian Institute of Road Safety Research) road accident database. Various data are obtained through this recorded information including the details of crashes, number of vehicles involved, crash severity, type of vehicle, and road geometry. Additional information like the weather condition, accident time and traffic volume is also recorded.

At each survey site in this study, tripod-mounted video cameras were placed to gather data on traffic movements. Additionally, intersection data specifically related to each site was gathered including its geometric characteristics, measurement details and photographic records. After the video data had been recorded, the video cameras were taken to the laboratory.

Data were collected at each intersection in Road Sections (RS) 10, 9, and 2, the details of which are as shown in Tables 1, 2, and 3, respectively. The sections registered a high number of fatal and serious injury crashes (see Figure 1). The intersection in Road Sections 10, 9, and 2 selected for this study had an access point (unsignalized single T-junction) connecting a four-lane two-way undivided major road with a two-lane two-way minor road. The selection of Road Sections (RS) 10, 9, 2 were based on two aspects, namely the number of accidents recorded and the road safety facilities provided. Although RS 5 registered the second highest number of crashes after RS 2, it had a three-leg unsignalized junction with a divider in the middle of the mainstream. That was the difference with the other RS.

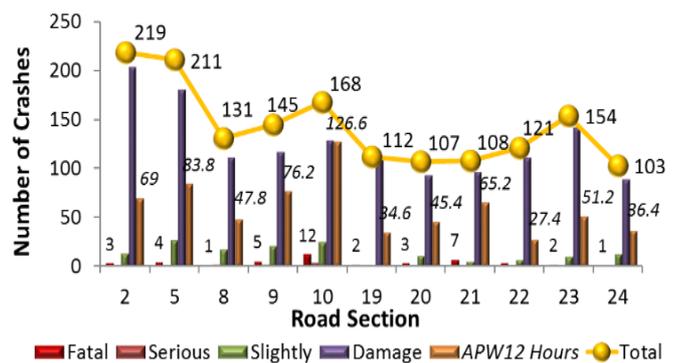


Figure 1: Number of accidents by type at the study location (2006 - 2010) during the 12-hour period

From the video recording of each intersection, a one-hour peak period (17:00 to 18:00) was used to analyse the RTV (right-turning vehicle) movements including gap acceptance and serious conflicts. To illustrate the general traffic flow conditions, Tables 1, 2 and 3 illustrate a 180-minute flow rate for all traffic movements at each unsignalized intersection.

Table 1: Traffic movements at Road Section 10

Movement	Minor Road	Major Road
Right-turns	244	66
Left-turns	184	80
Eastbound through	-	1397
Westbound through	-	1111

Table 2: Traffic movements at the RS 9 intersection

Movement	Minor Road	Major Road
Right-turns	182	47
Left-turns	145	303
Eastbound through	-	3316
Westbound through	-	2754

Table 3: Traffic movements at the Road Section 2 intersection

Movement	Minor Road	Major Road
Right-turns	125	95
Left-turns	30	123
Eastbound through	-	6707
Westbound through	-	4691

2.1 Data Reduction

Following the data collection process, the data related to each site were reduced to obtain necessary information for further analysis. The reduction process began with reviewing the site video and obtaining the turning movements and other traffic characteristics on the major road. For the data at each site, the goal was to obtain a minimum of 100 right-turning vehicles. However, some sites did not have 100 RTVs within a one-hour time frame; therefore, extra hours were needed for those sites. From the three sites, a total of 818 gaps were identified including accepted and rejected gaps. Of those, 170 and 143 gaps were related to passenger car RTVs and motorcycle RTVs, respectively. Only passenger cars and motorcycles were included in this study.

3. Analysis of the Gap Acceptance and Serious Conflict for Right Turning Vehicles

Observations of the RS 10 video recording revealed 107 samples in total, showing the accepted gaps of vehicles once they began a right turn into the major road from the minor one while 133 samples were noted in which gaps were rejected, causing the vehicles to wait until the next gap appeared. These results are illustrated in Figure 3. Observations of the RS 9 video recording revealed 100 samples in total, showing accepted gaps of vehicles once they began a right turn into the major road from the minor one while 139 samples were noted in which gaps were rejected, causing the vehicles to wait until the next gap appeared. The gap pattern defined here was identical to that of the RS 10 point of access. Meanwhile, for RS 2, 105 samples in all were noted where vehicles making right turns into the major road from the minor one accepted gaps whereas the study gathered 264 samples in which gaps were rejected.

This analysis shows that accepted gaps involve the patterns and times of gaps accepted by RTVs when making right turns. Many gaps were rejected by the RTVs. So, when making right turns, RTVs waited the longest at gaps that were rejected. The RS 9 and RS 10 junctions with no traffic signals are presented in Figure 2. On the other hand, RS 2 had a traffic signal approximately 100 meters from the junction.

Figure 2 shows the gaps (unit: -second). The graphic image shows how RTVs rejected or accepted gaps. Figure 2 and Figure 3 illustrate four and five types of gap patterns for right-turning vehicles respectively:

- i) **Gap 1 definition:** the space between two vehicles in lane 1 or lane 2. The first vehicle in the pair passes the RTV, while the second might allow the RTV to make a right turn.
- ii) **Gap 2 definition:** the space between two vehicles in lane 3.
- iii) **Gap 3 definition:** the space between one vehicle in lane 1 or lane 2 that has immediately gone past the RTV, and the other vehicle in lane 3.
- iv) **Gap 4 definition:** the space between one vehicle in lane 3 that has immediately gone past the RTV and the other in lane 1 or 2.
- v) **Gap 5 definition:** the space between one vehicle in lane 1 or lane 2 that passes the vehicle queued at the front, and then the one that follows the other vehicle in lane 5.

The analysis indicates the pattern of the gap and the time of gap accepted by the RTV when performing a right-turn equating to the accepted gap. In contrast, the rejected gap is the longest gap for which the RTV refused to turn right.

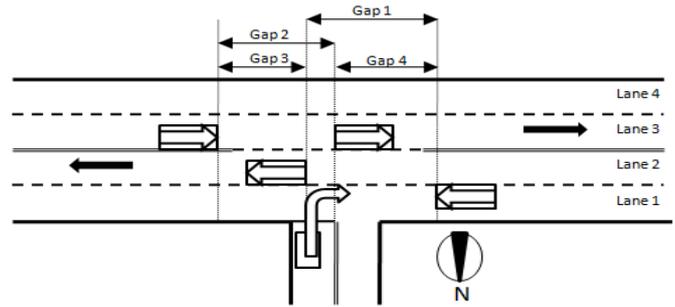


Figure 2: Four types of gaps accepted or rejected by vehicles-turning right at RS 9 and 10 non-signalized T-junctions.

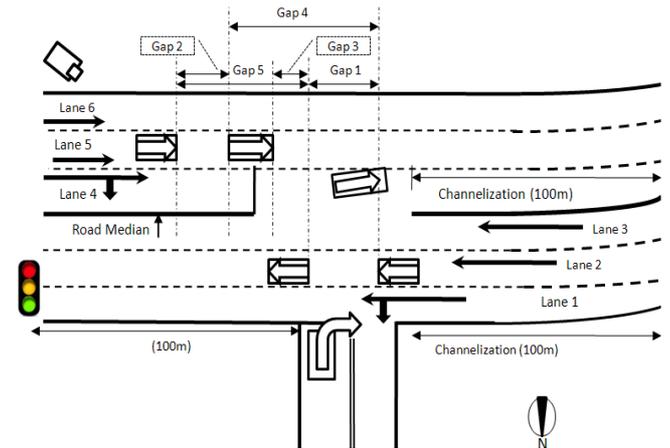


Figure 3: Five types of gaps accepted or rejected by vehicles turning right at the non-signalized T-junction of RS 2

Figure 4 shows the frequency of accepted gaps by gap patterns at the junction in RS 2, which was the subject of this study. Gap 3 pattern recorded the highest frequency of accepted gaps (41). Gap 5 and Gap 1 patterns had the second and third highest frequency of accepted gaps with 33 and 32 accepted gaps, respectively. However, Road Section 2 did not record any serious conflicts.

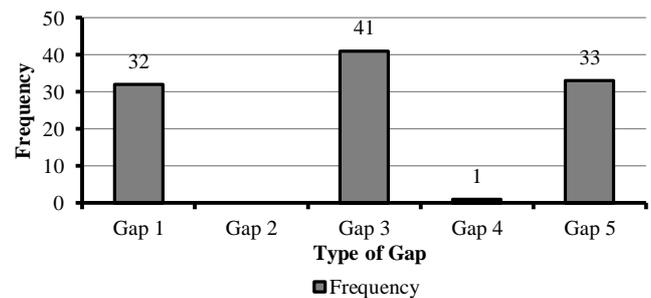


Figure 4: Types of gap frequencies in RS 2

Figure 5 shows the frequency of accepted gaps and the number of serious conflicts by gap patterns in RS 9. Again, Gap 3 pattern had the highest frequency of accepted gaps (49) and also the highest number of serious conflicts (5).

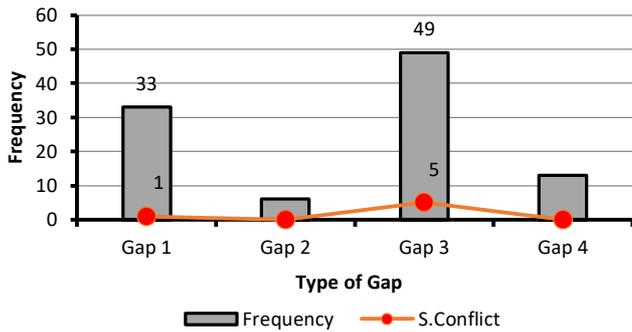


Figure 5: Types of gap frequencies in RS 9

Figure 6 below shows the frequency of accepted gaps and the number of serious conflicts by gap patterns at the junction in RS 10 in the study. Gap 3 pattern recorded the highest frequency with 75 gaps accepted and it also had the maximum number of serious conflicts with 13 cases.

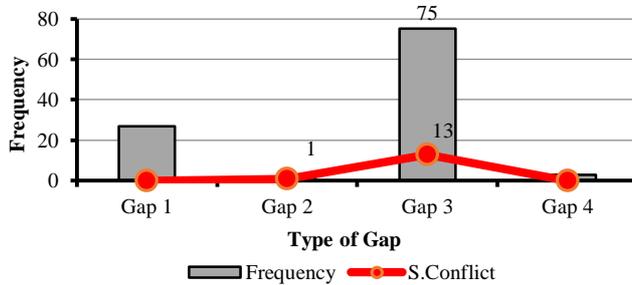


Figure 6: Types of gap frequencies in RS 10

3.1 Gap Patterns

Fajaruddin (2013) developed a serious conflicts model by using logistic regression methods and found that a speed of less than or equal to 60 kph and gap pattern 3 were the significant factor. The researcher described that serious conflicts were likely to arise in the Gap 3 pattern.

In each section and for all types of gap patterns, an average gap was obtained as illustrated in Figure 7. As demonstrated in the figure, gap patterns 2, 3, and 4 show a downward trend from Road Section 2 to Road Section 10. However, gap pattern 1 shows the opposite trend. For instance, in Road Section 2, a result of 10.24 seconds was obtained for gap pattern 3. Next was RS 9 with 9.3 seconds while RS 10 had the lowest result at 6.6 seconds. As mentioned earlier, safety facilities had been built at RS 2 junction with the important features being the channelisation of the intersection linking the minor roads (2 lanes) and major roads (6 lanes) and the close proximity of the traffic lights.

It is envisaged that this would have an influence on lengthening the gap acceptance. On the other hand, the RS 10 junction that was chosen had no provision of safety facilities as it was a non-channelised junction connecting the minor roads (2 lanes) and the major roads (4 lanes). The acceptance of gaps here was below the average RS 2 gap. This observation was supported by the gap acceptance behaviour analysis models which found that the existence of channelisation at the intersection and the location of traffic lights at a relatively close distance to an access point can cause right-turning vehicles to accept longer gaps.

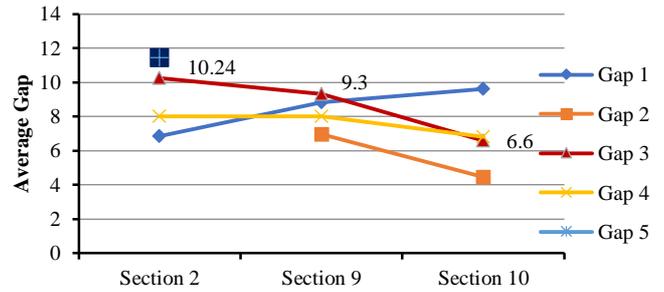


Figure 7: Average gap pattern analysis for intersections in all Sections

3.2 Type of Serious Conflicts

The original proposals for studies of traffic conflicts as outlined in the Traffic Conflict Technique were developed by Perkins and Harris (2012). These have been utilized as an alternate method in evaluating intersection accident probability. The main benefits of this method are the identification and solution of the problems concerning the potential for accidents in a more proactive form. This means that it is unnecessary to wait a number of years until sufficient accident data have been accumulated before conducting any analysis. Thus, if its application was systematic, studies of traffic conflicts might allow traffic engineers to keep abreast or ahead of changes in how issues related to accidents develop. Serious conflicts in RTV movement were analysed for the model. This study categorized types of conflict into two groups for simplicity, namely angular conflict and nose-tail conflict as shown in Figure 8. For specific research purposes, major conflicts were categorised as situations involving near misses including quick deceleration, avoiding collisions by stopping, use of emergency brake and swerving violently.

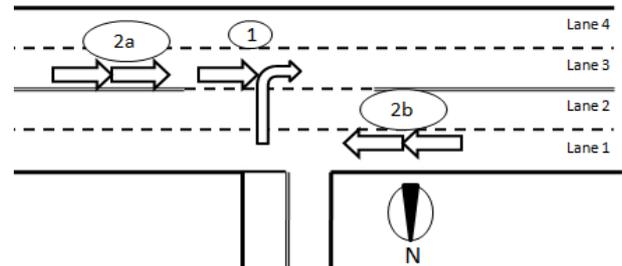


Figure 8: Type of serious conflicts at a non-signalised T-junction; 1: angular, 2a and 2b: nose-tail

Figure 9 shows the frequency of nose-tail serious conflicts at the RS 9 junction. In all, the highest number of major conflicts was noted for nose-tail conflicts with 6 cases. There were three cases with 4-second gaps and two cases with 5-second gaps.

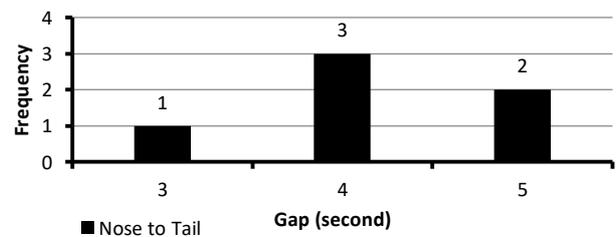


Figure 9: Serious nose-tail conflicts at the RS 9 non-signalised T-junction

Figure 10 shows the frequency of serious conflicts by type, (angular and nose to tail) at the RS 10 junction. In all, a higher recorded number in terms of major conflicts was for nose to tail conflicts (nine cases) compared to angular conflicts (five cases). For both nose to tail and angular conflicts, 5-second gaps had the maximum number of cases with four and three cases, respectively.

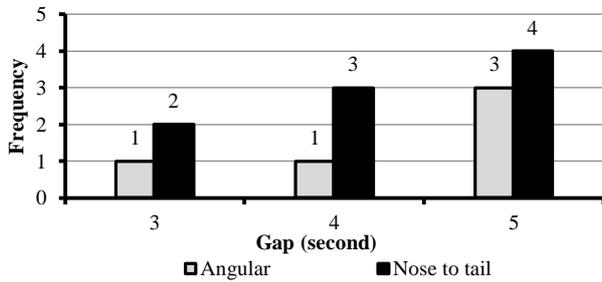


Figure 10: Two types of serious conflicts: angular and nose to tail at the RS 10 non-signalised T-junction

3.2.1 Other Variables

From the video data, additional information was collected on the traffic velocity on the major road, the type of right-turning vehicles, and the vehicle types (first and second vehicles) creating the measured gap on the major road.

3.2.2 Basic Analysis of Gap Acceptance and Serious Conflict

Figure 11 illustrates the right-turning vehicle frequency per gap size at the RS 9 intersection. Six-second and seven-second accepted gaps occurred most frequently. Only 6 cases were involved in serious conflicts. As for the type of vehicle, the RTV proportion included passenger cars (61%), motorbikes (28%), vans (5%), and lorries (6%).

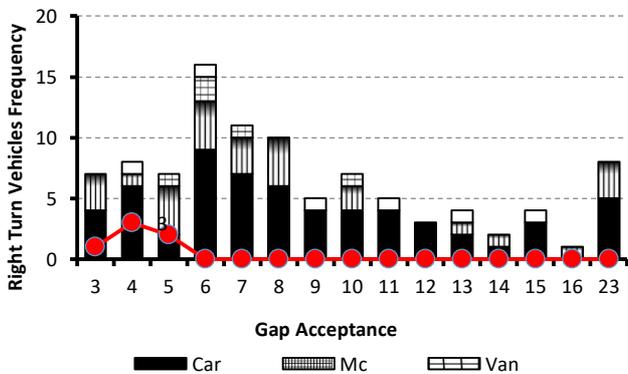


Figure 11: Accepted gap frequency by type of RTV with serious conflicts at the RS 9 junction

In the analysis, some sites experienced a shortage of data during the peak hour with less than 100 RTVs. We decided to analyse an extra hour to at least reach 100 RTVs. Figure 12 represents the type of right turning vehicle frequency against gap size at road section 10 intersection. Out of 107 samples showing an accepted gap, the number of serious conflicts with less than a 6-second gap size was 14 cases for an hour of video analysis. This figure can explain that the shorter the gap size, the higher the chances of a conflict occurring. In terms of the vehicle types making right turns at this junction, the respective proportions for motorbikes, passenger cars, vans, and lorries were found to be 60%, 24%, 14%, and 2%.

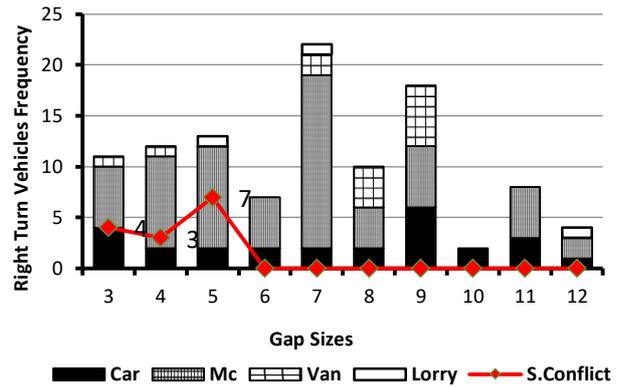


Figure 12: Type of turning vehicle frequency against gap size with conflict at RS 10 junction

Figure 13 illustrates the right turning vehicle frequency per gap size at Road Section 2 intersection. Six-second and seven-second accepted gaps occurred most frequently. Out of 107 right turning vehicles, there were no cases of serious conflict. The proportion by vehicle type of RTV for passenger cars, motorcycles, vans, and lorries were 57%, 35%, 7%, and 1%, respectively, as shown in Figure 13. This indicated that the presence of right channelization at the intersection had minimized the conflict and eased the driving task. If this channelization was used properly, there would be a reduction in vulnerable users' exposure to conflicts with vehicles although vehicle movements would not be hindered.

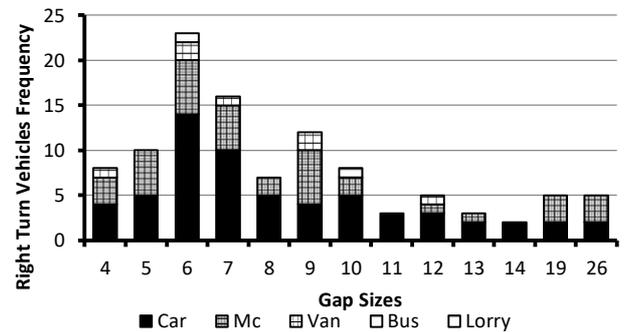


Figure 13: Accepted gap frequency by type of RTV at the RS 2 junction

3.2.3 Analysis of Critical Gap

Over half a century ago, Raff et al. (1950) developed a macroscopic model to estimate the critical gap. To provide a definition of the critical gap, the researchers gave the value of t_c , where the functions $1 - Fr(t)$ and $Fa(t)$ intercept. The value of t_c at which,

$$Fa(t) = 1 - Fr(t) \tag{1}$$

The method is preferred in a number of countries due to its simplicity while many studies continue to implement it today. The Raff Method and the Logit Method are also recognized as Logistic Regression, SAS (1994). A study conducted by Miller (1972) claimed that the Raff and Logit approaches both contained bias in relation to how the critical gap was determined. However, Harwood et al. (1999) proved that the bias about the gap critical value was likely to be small.

Figures 14, 15, and 16 illustrate how the Raff Method can be applied to the accepted and rejected gap data in actions involving right turns. When the data were analysed, the graph incorporated only right turns that did not involve the decision to accept or reject the gap being disturbed by other vehicles. The Raff Method involves determining the cumulative distribution of gaps that are rejected gaps and matching

this with the cumulative distribution of gaps that are accepted. Meanwhile, the intersection point of the rejection and accepted curves allowed the critical gap to be ascertained. The findings were as follows: for the RS 2, RS 9 and RS 10 intersections, the respective critical gaps were 6.0 seconds, 5.8 seconds, and 4.5 seconds.

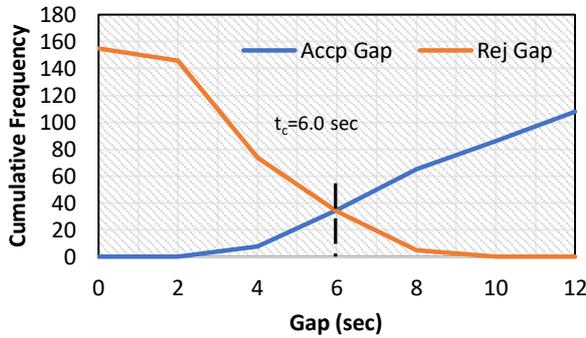


Figure 14: Cumulative distributions of accepted or rejected gaps versus gap at RS 2 Intersection

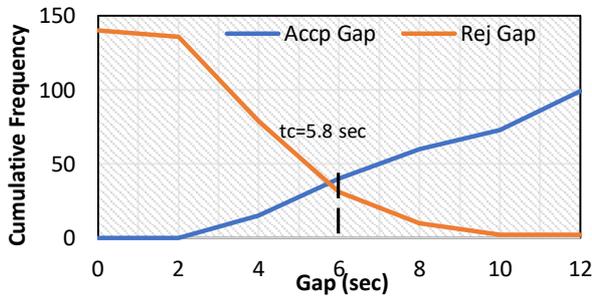


Figure 15: Cumulative distributions of accepted or rejected gaps versus gap at RS 9 Intersection

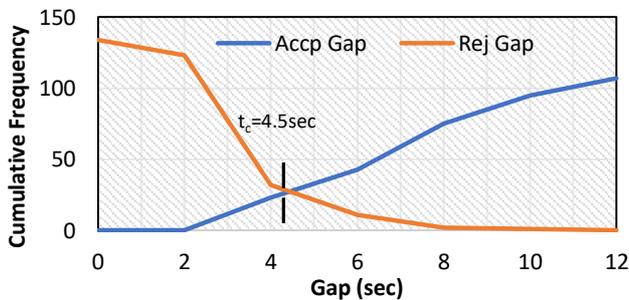


Figure 16: Cumulative distributions of accepted or rejected gaps versus gap at RS 10 Intersection

4.0 Gap Acceptance Behavior Models

4.1 Development of Models

Two options are available to drivers, namely the acceptance or rejection of gaps before crossing the junction. This research has generally utilized logistic regression in modelling discrete choice behaviour of this type; whereby it was regarded as an appropriate approach in this study. Driver decisions might be dependent on how long the provided gap is, the oncoming vehicle's speed, manoeuvres of vehicles, and intersection waiting time. The sum of the decisions taken by the driver who is turning right is termed the decision utility. In functional form, the utility of the decision is given as follows:

$$U_i = V_i + \epsilon_i \quad (2)$$

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 of the randomly selected driver's tendency to accept gap i , which is expressed as:

$$V = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (3)$$

Where β_0 = is constant, $\beta_1, \beta_2, \dots, \beta_n$ = are the regression coefficients, and X_1, X_2, \dots, X_n = other explanatory variables. The likelihood of a randomly chosen driver accepting gap, (P_{rt}) is presented by the logit function:

$$P_{rt} = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n)}} \quad (4)$$

It is possible to transform the logit function into a linear equation, thus:

$$\ln\left(\frac{p_{rt}}{1-p_{rt}}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (5)$$

Where P_{rt} = Right-turn vehicle probability. The critical gap is the x -value, obtained by substituting P with 0.5.

Table 4: Description of variables for gap acceptance model

Abbr.	Description
RT	RT = 1 if vehicle turns right at a gap, and 0 otherwise.
Gap	Gap which is rejected or accepted (sec).
Car	Car = 1 if the RTV is a car, and 0 otherwise.
Mc	Mc = 1 if the RTV is a motorcycle, and 0 otherwise.
Rider	Rider = 1, if the RTV is a motorcycle with a single rider, and 0 otherwise.
McP	Mc = 1 if the RTV is a motorcycle with a passenger, and 0 otherwise.
Vn	Vn = 1 if the RTV is a van, and 0 otherwise.
AS	Approach speed of second vehicle that allows the RTV into mainstream (kph).
SPLT	SPLT60 = 1 if approaching speed of the second vehicle that allows the RTV into the mainstream is less than or equal to 60kph.
Conf	Conf = 1 if a serious conflict has occurred (i.e., angular or nose to tail), and 0 otherwise.
Nose-tail	Nose-tail = 1 if nose-tail of a serious conflict has occurred, and 0 otherwise.
Asc	Asc = 1 if angular of a serious conflict has occurred, and 0 otherwise.
Gap4	Gap3 = 1 if the gap is of gap pattern 4 in Figure 3.1, and 0 otherwise
Gap3	Gap3 = 1 if the gap is of gap pattern 3 in Figure 3.1, and 0 otherwise
Gap2	Gap2 = 1 if the gap is of gap pattern 2 in Figure 3.1, and 0 otherwise
FPC,FMc,FLorry, FBus	FPC, FMc, FLorry and FBus = 1 if the first vehicle passing the RTV is passenger car, motorcycle, lorry, or bus; otherwise, 0.
SPC,SMc,SLorry, SBus	SPC,SMc, SLorry and SBus = 1 if the second vehicle is a passenger car, motorcycle, lorry or bus that allows the RTV; otherwise, 0.
Chnlz	Chnlz=1 if the RTV stops for a while at the channelisation before continuing the turning on the major road; otherwise, 0.

As mentioned earlier, the data collection process included three intersections, resulting in a total of 818 observations. Of those, 351 right turn vehicles (RTV) were identified and the five types of vehicles involved in the analysis were motorcycles (138), passenger cars (143), vans (42), and heavy vehicles (28). Binary logit models were created to fit the data which enabled the impact that several factors had on the drivers' behaviour in terms of gap acceptance to be understood. In identifying the significant variable, a stepwise selection approach was utilised. The development of the models utilized the Logistic

Regression Method in SPSS 23. In determining the level of significance, the stepwise selection approach gave 0.05. The definitions of each attribute utilized in developing the model for gap acceptance behaviour are listed in Table 4.

Table 5 shows the outcomes of the estimation of parameters. To determine the gap acceptance behaviour, four different models were created. Models 1 and 2 were calibrated for right-turning motorcycles (single rider) and right-turning passenger cars, respectively. Model 3 and model 4 illustrate the simpler and the more detailed systems showing every type of RTV. The outcomes showed that the models' R^2 values came out high with respective values of 0.65, 0.73, 0.63, and 0.70, for Models 1, 2, 3, and 4. The hit ratio of every model was over 75% which indicated that the data were effectively reflected by the models.

Following several efforts to obtain calibrations of the model of gap acceptance as shown in Table 5, the variables remaining in Models 1, 2, 3, and 4 were the gap, the SPC (the second vehicle to pass an RTV was a passenger car), SMC (the second vehicle to an RTV was a motorbike), ASC (angular serious conflict), NTSC (nose-tail serious conflict), TL (traffic lights), the rider, and the Chnlz (channelisation). These variables were significant factors in drivers' decisions to turn right.

Table 5: Gap acceptance models for RTVs

Variable	Model 1 (Rider)	Model 2 (Car)	Model 3 All Vehicle Types (Simplified model)	Model 4 All Vehicle Types (Detailed model)
	Parameter	Parameter	Parameter	Parameter
Constant	-5.83 (58.18)***	-5.08 (76.43)***	-4.42 (221.98)***	-5.72 (154.34)***
Gap	0.90 (72.55)***	0.96 (86.07)***	0.81 (213)***	0.90 (208.08)***
SPC	2.18 (17.91)**	-	-	0.76 (7.02)**
SMc	2.62 (10.77)***	1.39 (4.21)**	-	1.62 (12.12)***
ASc	2.70 (5.18)**	-	-	3.23 (8.54)***
NTSc	-	2.68 (3.15)*	-	3.57 (9.60)***
TL	-1.40 (9.12)***	-0.72 (3.38)*	-	-0.60 (5.36)**
SRider	-	-	-	0.69 (8.29)***
Chnlz	-	-2.17 (11.43)***	-	-1.22 (7.02)***
N	138	143	818	818
Nagelker keR ²	0.65	0.73	0.63	0.70
H.R- Right Turn	83%	76%	77%	82%
H.R- Total	84%	82%	83%	87%

*, **, ***=Significant at the 90%, 95% and 99% level, respectively H.R.= Hit ratio.

If the variables of angular and nose-tail serious conflicts have positive signs, this is an indication that an RTV that was the cause of the major conflict had the tendency to begin a right turn when a gap was short. On the other hand, major conflicts were found to be more common if a gap was shorter.

The positive sign of the SMC and SPC variables in Model 1 indicates that an RTV would probably accept a gap that was short. In Model 2, the negative signs of the parameters for traffic lights (TL) and channelisation (Chnlz) suggest that an RTV would probably accept a gap that was longer. A simplified model for each type of vehicle, Model 3 was utilised to calculate the average critical gaps for

each vehicle type. This is outlined in the following section. A version with more details for each type of vehicle is provided in Model 4. The variables of SPC, SMC, ASC, NTSC, TL, rider, and channelisation were found to be significant in the model.

4.1 Critical Gap Analysis for RTVs Considering Serious Conflicts

Estimations of each critical gap are presented in Table 6, the definition of which is the space that an RTV accepts with a probability of 50%. Models 1, 2, and 3 allowed calculations of the critical gaps for motorbikes, cars, and every type of vehicle, by allocating $P_{\pi}=0.5$ for every model; if they experience conflict, $P=1$, and if not, $P=0$. The critical gaps for motorcycles (single riders), passenger cars and RTV for all vehicle types in RS 2, 9, and 10 were 6.48 seconds, 5.99 seconds and 5.46 seconds respectively. By using Model 1 (motorcycle single rider), if RTV single rider is involved in angular serious conflict, the critical gap becomes shorter at 3.48 seconds. Meanwhile in Model 2 (car passenger), if RTV passenger car is involved in nose to tail serious conflict, the critical gap will be 2.5 seconds. Thus, both vehicles can be identified as the most dangerous RTV from the minor road to the main stream. If they experienced serious conflict, the probability of serious injuries was very high. Although, passenger car showed shorter critical gap with conflict than single rider, the prospect of a single rider experiencing serious injury or fatality was higher than a passenger car driver.

Every critical gap assessed at the intersections was less than those established in Malaysian Standards MS (1987) (7 seconds) and United State Highway Capacity Manual USHCM (2000) (7.5 seconds). In particular, there was a large difference between the standards and the critical gap results for passenger cars involved in serious conflicts. A passenger car engaged in a serious conflict would accept gaps that were too short to allow a safe right turn. Drivers of RTVs seemed to purposefully begin a right turn in overly short gaps with no awareness of the danger. They might also expect that the other drivers on the major road would decelerate voluntarily. If motorcycles turned right, the riders in particular were exposed to potentially higher risk of involvement in fatal and major accidents.

Estimations of the critical gaps are shown in Table 6; the definition of which are the gaps that RTVs accept with a probability of 50%. The critical gaps for motorcycles, cars, and all vehicle types were calculated from Models 1, 2, and 3 by setting $P_{\pi}=0.5$ for each of the models and if experience conflict=1, and 0 otherwise. The critical gaps for motorcycles (single riders), passenger cars and RTV for all vehicle types in RS 2, 9, and 10 were 6.48 seconds, 5.99 seconds and 5.46 seconds respectively. By using Model 1 (motorcycle single rider), if RTV single rider is involved in angular serious conflict, the critical gap becomes shorter at 3.48 seconds. Meanwhile in Model 2 (car passenger), if RTV passenger car is involved in nose to tail serious conflict, the critical gap will be 2.5 seconds. Thus, both vehicles can be identified as the most dangerous RTV from minor road to the main stream. If they experienced serious conflict, the probability of being involved in serious injuries was very high. Although passenger cars showed shorter critical gap with conflict than single riders, the prospect of single riders being involved in serious injury or fatality were higher than passenger car drivers. Matsumoto et al. (2016) defined motorcyclists as Vulnerable Road Users (VRU) because almost half of road accident victims every year around the world were identified as motorcyclists, cyclists and pedestrians.

Every critical gap measured at the intersections was less than that established in Malaysian Standards (ATJ 11/87) (7 seconds) and USHCM (2000) (7.5 seconds). In particular, there was a large difference between the standards and the critical gap results for passenger cars involved in serious conflicts. A passenger car engaged in a serious conflict would accept gaps that were too short to allow a safe right turn. Drivers of RTVs seemed to purposefully begin a right turn in overly short gaps with no awareness of the danger. They might also expect that the other drivers on the major road would decelerate voluntarily. If motorcycles turned right, the riders in particular were

exposed to potentially higher risk of involvement in fatal and major accidents.

During peak hours, since the major roads experienced extremely high traffic volumes but had no traffic lights, drivers of RTVs had limited opportunity to choose a safe gap. At times, it was problematic for them to wait until a safer gap appeared. Reducing serious conflicts would decrease the occurrence of fatal and serious accidents. For locations where the traffic volumes and accidents involving RTVs were relatively high, it is recommended that a number of countermeasures be introduced so the shorter gaps can be lengthened through: 1) installation of traffic signals to provide sufficient gaps for drivers on minor roads to cross onto major roads; 2) warning drivers on major roads that vehicles might be about to cross with signboards placed ahead of the junction; 3) cautioning drivers on major roads to decelerate and widen the distance from the car in front; and 4) installation of small traffic islands at junctions to allow RTVs (especially motorbikes) to stop at this point before they enter the mainstream traffic. This would also provide the benefit of reducing nose-to-tail conflicts.

Table 6: Comparison of the critical gaps

	Critical Gap (tc)
Single Rider critical gap	6.48
Single Rider critical angular serious conflict	3.48
Passenger Car critical gap	5.99
Passenger Car with nose-tail serious conflict	2.50
All vehicles	5.46
Malaysian Standard	7.0
USHCM 2000	7.5

5.0 Discussion

Based on Model 1 (single rider) and Model 2 (passenger car), it was found that motorcycle single riders were likely associated with angular serious conflicts while passenger car were associated with nose to tail serious conflicts. This study found that serious conflict gap acceptance for motorcycles, passenger cars and other vehicles were between the range of 0-5 seconds as shown in Figure 11 and Figure 12. Both angular serious conflict and nose to tail serious conflict variables were significant with 99% confident level in all vehicle types behaviour.

This study also identified that motorcycle single riders were classified as risky RTVs from the minor road to the main stream at unsignalised intersections compared to other vehicles. Model 1 (motorcycle of single rider behaviour) showed critical gap with serious conflict at 3.48 seconds which was inadequate for riders to make a safe right turn. The potential of serious injuries or fatality was likely to be higher. Thus, more attention needs to be given to overcome this issue. Installing traffic lights and providing road safety facilities such as channelisation might be practical to reduce serious injuries and also to save lives. Unsignalised intersection at RS 2 could be a proper example. Meanwhile RS 10 indicated critical gap of 4.5 seconds for all RTVs as shown in Figure 16 and an average for gap pattern 3 at 6.6 seconds (Figure 7) which was less than 7 seconds under Malaysia Standards. It indicated that RS 10 did not comply with the standard requirements, thus, immediate countermeasures were required.

6.0 Conclusion and Recommendation

This research has analysed the factors related to fatal and serious accidents in order to explain dangerous vehicle movements. The results are as follows:

- (1) Gap acceptance models at access points were developed using logistic regression. If these models were applied to the behaviour of vehicle drivers using RS 2, 9 and 10, a number of variables

were identified as significant factors affecting the decision of the drivers to turn right. These included the gap; whether the second vehicle going past the RTV was a passenger car, motorbike or a motorbike with a single rider; serious angular or nose-tail conflict; traffic lights, riders, and channelisation.

- (2) The application of the models to the RS 2, 9, and 10 combination showed how positive signs in a number of variables indicated that an RTV had the tendency to begin a right turn in a short gap. These included serious angular or nose-tail conflicts and whether the second vehicle was a motorcycle, motorcycle with a single rider or a passenger car. Positive signs observed in the Model 1 variables suggested the likelihood of an RTV accepting gaps that were shorter. The negative signs of the traffic light and channelisation parameters indicated that the RTVs were likely to accept a longer gap.
- (3) The estimated critical gaps were short compared to the Malaysian Standard. Drivers sometimes appeared to intentionally start turning right during a very short gap. Several countermeasures were proposed to lengthen the short gaps.

To avoid the occurrence of fatal and serious accidents at access points, it is necessary to carefully identify the main problem. According to this research, one proposal is for gap pattern 3 and the critical gaps at access points (intersections with no signals) to be utilised as the foundations for developing useful countermeasures. For instance, if the points of access have an average gap in pattern 3, and the critical gaps at the RTV point of access are below 7 seconds (Malaysian Standard), countermeasures such as channelisation or traffic lights should be considered. In other words, it is possible to utilise gap pattern 3 and the critical gap as a useful means of implementing countermeasures at every junction without signals especially in Malaysia and also in various other countries. Moreover, the study might be used as a reference for vehicle-to-vehicle V2V technology which involves the transmission of wireless data from one vehicle to another. The main objective of this means of communicating is to prevent potential accidents at junctions without signals, according to Anaya et al. (2013).

The results discussed above indicate that the models developed in this study may be usefully applied on rural roads in Malaysia. Hence, the authors contend that these research findings might serve as a reference point to benefit engineers planning to improve or design multi-lane roads in rural areas. Of greater importance is how the effective models of gap acceptance behaviour that this study has developed can be applied in measures to improve road safety. The models might also form the basis for future research in a number of developing countries including Malaysia.

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