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Gap acceptance of violators at signalised pedestrian crossings

Abstract

Gap acceptance of violating pedestrians was studied at seven stretches of signalised pedestrian crossings in Singapore. The provision of the traffic light signals provide a 'safer' crossing option to these pedestrians, as compared to uncontrolled crossings and mid-block arterial roads. However, there are still people choosing to cross at the riskier period (Red Man phase). The paper discusses about the size of traffic gaps rejected and accepted by pedestrians and the behaviour of riskier pedestrians (those adapting partial gap). The likelihood of pedestrians accepting gaps between vehicular traffic as a combination of different influencing independent variables such as traffic, environmental and personal factors was studied and modelled using logistic regression.

Highlights:

Gap acceptance at signalised pedestrian crossings > longer accepted gaps at near end of crossings compared to far end of crossings > 20% of violators adopted partial gaps > gap, gap type, stage of crossing and crossing speed affect gap acceptance

Keywords: gap acceptance, signalised pedestrian crossing, violators

Gap acceptance of violators at signalised pedestrian crossings

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1.0 Introduction

Road junctions are critical locations where conflicts between different groups of road users occurred. Even after signalisation, accidents still occur at these locations. A study in USA revealed a list of personal and environmental factors that affects severity of injuries sustained by the pedestrians in road traffic accident (Clifton *et al.* 2009). It was found that pedestrians who cross against the traffic signal are among those who suffered greater injury risk. In Sweden, most of the pedestrian accidents at signalised crossings are due to a turning vehicle hitting a pedestrian during Green Man, and a red walking pedestrian being hit by a vehicle (Garder 1989). Other likely causes of pedestrian accidents include illegal pedestrian movements, negligence, inappropriate management and lack of reasonable facilities to cross the streets (King *et al.* 2009, Chen *et al.* 2011, Wang *et al.* 2011). Since the number of accidents involving violating pedestrians can be reduced by reducing the number of violators, it is pertinent to study pedestrians' violating behaviour.

Gap acceptance studies done on motorists have mainly been targeted to study delay and capacity at intersections. In the case of pedestrians, capacity is less of an issue since more than one pedestrian can cross at anytime. More importantly, the study of pedestrian gap acceptance is to assess the accident risk at junctions (Yang *et al.* 2006). At a signalised junction, a gap acceptance situation arises when a non-compliant pedestrian attempts to cross during Red Man (RM) phase. A non-compliant (violating) pedestrian looks out for available gaps along the vehicular stream to cross. If the perceived vehicular gap is more than a minimum safe gap, it is accepted and the pedestrian crosses (Brilon *et al.* 1999, Hamed 2001, Chen *et al.* 2010, Zhao 2012). Otherwise, it is rejected and the pedestrian waits for the next available gap.

The presence of available gaps along the vehicular stream is one of the main factors influencing the tendency of pedestrian to disregard the traffic light signals. Individuals have different minimum acceptable gap (in seconds), depending on the level of risk that he or she is willing to take and his or her personal limitation (such as age) (Simpson *et al.* 2003, Oxley *et al.* 2005, Velde *et al.* 2005). Factors influencing gap acceptance include traffic conditions (e.g. oncoming vehicle type, conflicting traffic movement type), situational conditions (e.g. being accompanied by others) and other personal characteristics (e.g. use of partial gap, pedestrian speed, whether the subject stops before crossing, age of the person) (Lobjois and Cavallo 2007, Yannis *et al.* 2010, Kadali and Perumal 2012). These non-compliant pedestrians are commonly known as violators who pose safety concerns to conflicting motorised vehicle streams. It is important to study this group of road users as their behaviours are usually random and unexpected.

In Singapore, there are two main types of signalised pedestrian crossings namely, junctions and mid-blocks. The signal cycle of a signalised pedestrian crossing is typically made up of the first few seconds of steady Green Man, followed by the Blinking Green Man and the Red Man. Most pedestrian crossing signals are attached with countdown-to-red pedestrian timers which start counting down after 6 or 10 s of steady green man and blink together with the green man for the last five seconds. At a typical signalised pedestrian crossing at a junction, pedestrians have to look out for left turning (junction with no slip road) and right turning (permissive filtering right turn phase) vehicles during the Green Man phase. (It is useful to note that Singapore is a left hand traffic country where motorists drive on the left side of the road). According to the Singapore Road Traffic Act, it is illegal for a pedestrian to cross during the Red Man phase (Road Traffic Act 1990). From the past 2009-2011 accident statistics (SPF 2013), it has been found that 22% of the pedestrian fatal accidents occurred at signalised pedestrian crossings. Of which, one in three such accidents occurred during the red man phase. The average age of these killed pedestrians is 52 years old and the accidents occurred during the off-peak hours. If these pedestrians were to obey the traffic signals, the chances that they become victims of road traffic accidents could be reduced. Accident records that the team has access to could not really identify detailed behaviour of the violators and hence it would be useful to analyse their behaviour via video footages obtained unobtrusively.

2.0 Past studies on gap acceptance

The Highway Capacity Manual defines the critical gap as the time (in seconds) below which a pedestrian will not attempt to begin crossing a street (TRB 2010). Chen et al. (2010) defined the time headway between two vehicles as the gap acceptance for a pedestrian to cross the road. The minimum acceptable gap is equivalent to the summation of time needed for the pedestrian to cross the roadway width (average walking speed = 1.2 m/s), decision time for pedestrian to cross (2 s) and the passing time of vehicle (assumed 0.72 s). Wang (2010) used cross gap and defined it as the distance divided by the vehicle speed on the time that the pedestrian tends to cross. The critical cross gap was found to be 4.43 s.

Kadali and Perumal (2012) studied pedestrians' gap acceptance at one mid-block location and described gap acceptance using lognormal regression. It was concluded that pedestrians' gap acceptance could be explained by pedestrian speed, crossing direction, partial gap, vehicle speed and pedestrian age. Yannis et al. (2010) found that distance from approaching vehicle, presence of illegally parked vehicles, size of approaching vehicle and presence of other pedestrians have important effect on the accepted traffic gaps.

A study done at signalised junctions in Beijing found that the average acceptable gaps by pedestrians and cyclists were 5.79 and 4.52 seconds, respectively (Wu *et al.* 2004). Discrete choice model of cyclist gap acceptance behaviour was used and the factors that influenced gap acceptance include large gap opening vehicles, large gap closing vehicles, left turning manoeuvre (in U.S. right-hand traffic convention) and stopping before crossing.

Past literature showed various forms of gap acceptance, however many were studied at uncontrolled crossings or mid-blocks of streets (Brewer *et al.* 2005, Wang 2010, Kadali and Perumal 2012). Though pedestrians who crossed during the Red Man (RM) phase (i.e. the violators) are almost equivalent to scenarios of jaywalking across uninterrupted traffic flow, in that the pedestrians would also have to look out for traffic which has the right of way, the decision to cross during RM may not be clear at the beginning of arrival at the waiting area. Not all who arrived at the RM phase chose to cross illegally, and many waited for the next

Green man (GM) to cross legally when they have the right-of-way. As there is an option of a later (GM) designated phase for these people to cross, the factors affecting the gap acceptance of non-compliant behaviour may be different from those along uninterrupted flow or uncontrolled crossing.

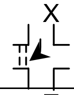
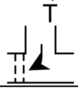
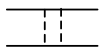
The objective of this research is to investigate non-compliant pedestrians' traffic gap acceptance at signalised pedestrian crossings during RM phase. The effects of traffic, situational and personal factors were investigated to model their influencing effects on gap acceptance. Predictors that were not considered in other past research but considered in this study include configuration of crossing, stage of crossing, whether the person is a high risk taker and conflicting traffic movement type. The results shall serve as important parameters in microsimulation modelling which typically assumed a constant value that is not representative of the real pedestrian behaviour (Wang 2009, Zhao 2012).

3.0 Methodology

3.1 Data collection

Seven stretches of signalised pedestrian crossings near transit stations were selected in the study (see Table 1). The crossings included three cross junctions, two T junctions and two mid-block pedestrian crossings. This is to cover different settings of motorised vehicular risk to the pedestrians. The crossings have a wide range of pedestrian and cyclist interactions, and the crossing widths and lengths vary from 2.8-6.2 m and 15-26 m, respectively. All the crossings have count-down to red pedestrian timers. Video cameras were used to capture footages of crossing behaviour of pedestrians from a vantage point (tied to an extended pole attached to a nearby lamp post) during the evening peak period. The coverage of the video included the waiting areas at two ends of the crossing, the actual crossing channel and the traffic signal. Data collection was conducted during non-raining weekdays (excluding Friday) evening peak hours (between 5-7pm) with at least one hour of uninterrupted recording for each location.

Table 1: Details of the selected signalised pedestrian crossings

Location	Location type	Crossing width (m)	Crossing Length (m)	Average Green Man time (s)	Average Blinking Man time (s)	Average Red Man time (s)	Number of observed cycles
1 - Admiralty	X	2.8	25.2	6	25	55	50
2 - Aljunied		3.5	20.8	6	19	104	27
3 - Yishun		3.0	25.4	6	24	85	88
4 - Bedok	T	3.3	14.8	6	18	62	62
5 - Boon Lay		2.8	18.5	6	20	69	57
6 - Tampines	Mid	4.9	21.8	10	22	87	46
7 - Simei		6.2	14.6	10	14	64	60

3.2 Data extraction

To calculate gap acceptance, all cases with a violator (who arrived and crossed during RM) were observed. The violators who started off within 1-2 seconds before the GM onset were excluded as there is likely to be no passing vehicle since it is the junction-wide all-red clearance time. A violator would typically look for an acceptable gap to cross. The conflict areas were defined as the yellow boxes shown in Figure 1. It is assumed that the violator treats the centre divider as a safe resting point and crosses in two stages, and the conflicting vehicle may change lane within the same channel. In other words, if there is an oncoming vehicle, the violator will consider if he or she can make it across to the centre divider before the vehicle touches the conflict area.

Hence, the extraction of gap rejection and acceptance can be studied in two separate stages namely, the near end and far end of each crossing activity (see Figure 2). For Stage (1), the violator starts off at the kerbside (known as near end crossing), looks out for conflicting vehicles within Conflict area (1) and makes a decision to cross when there is an appropriate gap. If there are two passing vehicles before the violator starts to cross, t_{vls1} and t_{vl1} are the timings where the second last vehicle and last vehicle touched Conflict area (1). t_{p1} refers to the time when the violator arrives at the waiting area, t_{p2} is the time when the violator steps onto the road, t_{p3} is the time violator reaches the centre divider and t_{vn1} is the time when the next passing vehicle touches the pedestrian crossing line.

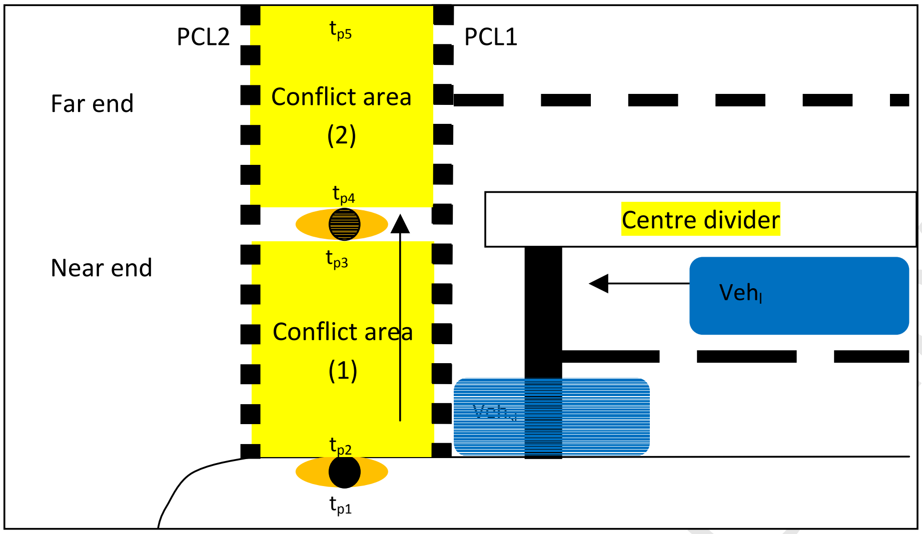


Figure 1: Schematic diagram of gap acceptance

Veh_l: Last passing vehicle, Veh_{sl}: Second last passing vehicle; PCL1: pedestrian crossing line 1; PCL2: pedestrian crossing line 2

For Stage (2), the violator, after crossing Conflict area (1), stops at the centre divider to look for a gap to cross the far end of the crossing during the RM phase. Similarly, t_{vls2} and t_{vl2} are the timings of the last two passing vehicles before the violator crosses. t_{p4} is the time violator moves off from the centre divider, t_{p5} is the time violator reaches the opposite end of the crossing and t_{vn2} is the time the first passing vehicle touches Conflict area (2) after the violator has crossed.

The time difference between two last passing vehicles (that touched the conflict area) before the violator has crossed is considered the rejected gap (Method 1). The time difference between the last passing vehicle and the next passing vehicle after the violator has crossed was the accepted gap. If there is no second last passing vehicle, then the rejected gap is measured by the time difference between the time the last passing vehicle touches the conflict area and the time of arrival of the violator (Method 2). If there is no passing vehicle before the violator starts to cross, the accepted gap was measured by the time difference between the time the violator starts to cross (touched the conflict area) and the time the first passing vehicle (after the violator has crossed) touches the conflict area. Only free-flowing passing vehicles are considered and a stream of vehicles (with no sizeable gap in between) is considered as a “long” vehicle. The gap acceptance/rejection data was recorded such that each direction (channel) of vehicular traffic and each direction of pedestrian traffic were in separate data strings. Only the last rejected gap (preceding the crossing event) was included in this study as it is deemed that the intention to violate at signalised pedestrian crossings may not be there when the person first arrived during the RM phase. It could be due to long waiting time or other factors (e.g. group following effect) during waiting that changes the person’s decision to violate.

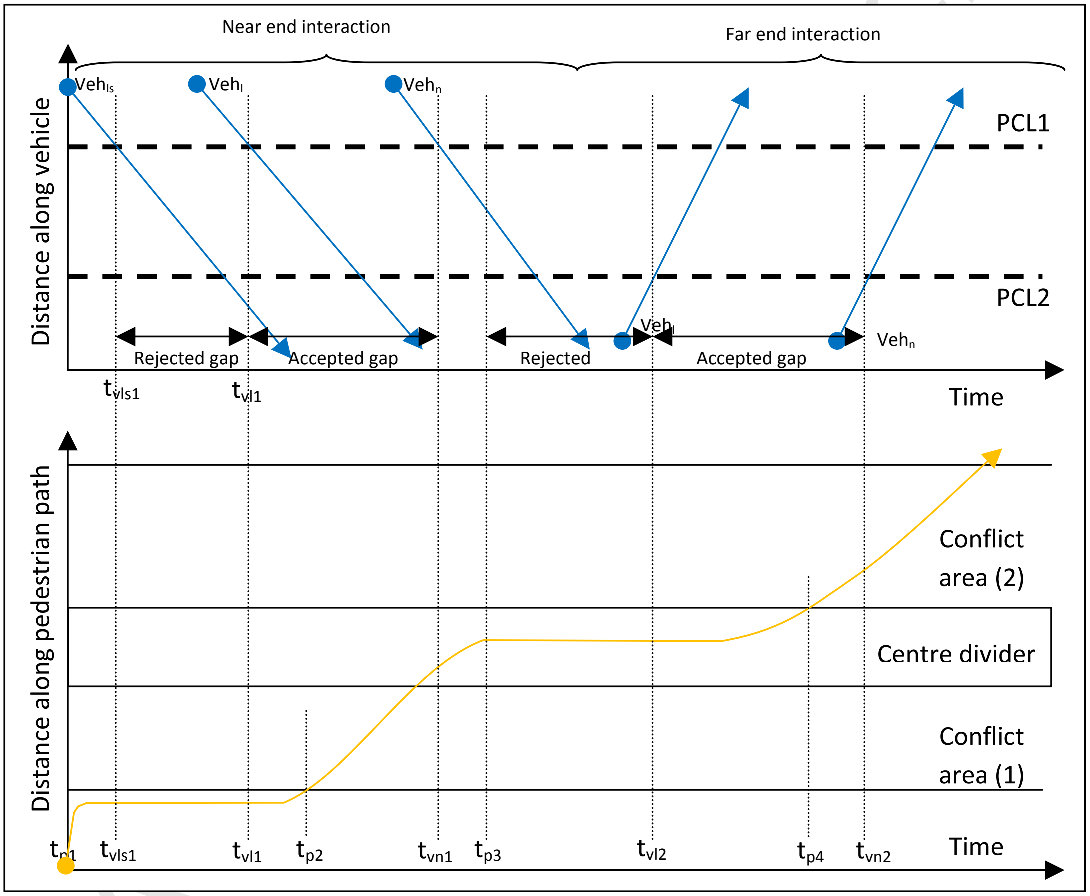


Figure 2: Distance-time graph

For Stage 1: Rejected gap = $t_{vl1} - t_{vls1}$ *(Method 1)* or $t_{vl1} - t_{p1}$ *(Method 2)*

Accepted gap = $t_{vn1} - t_{vl1}$ or $t_{vn1} - t_{p2}$

For Stage 2: Rejected gap = $t_{vl2} - t_{vls2}$ or $t_{vl2} - t_{p3}$

Accepted gap = $t_{vn2} - t_{vl2}$ or $t_{vn2} - t_{p4}$

The second part of the study involves modelling the probability of gap acceptance with various influencing independent variables including traffic condition, situational condition and personal characteristics. Table 2 summarises the continuous and discrete variables that were deemed to influence the likelihood of gap acceptance.

Table 2 List of influencing variables on the likelihood of gap acceptance/rejection

Category	Variables	Type	Accept/Reject
Traffic condition	*Available gap*[1] (in seconds)	Continuous	-
	Gap type Method 1 – With 2nd last passing vehicle (rejected gap)/last passing vehicle (accepted gap) Method 2 – Without 2nd last passing vehicle/last passing vehicle [reference level]	Categorical	 38/147 66/41
	Vehicle type [Last (rejected gap) or next (accepted gap) passing vehicle] Car – including taxis MC –Motorcycle LGV – Light goods vehicle HGV – Heavy goods vehicle (including bus)	Categorical	 66/130 7/11 16/18 15/29
	Conflicting traffic movement HR – Horizontal right turn/U-turn OR – Opposite right turn S - Straight	Categorical	 8/22 6/2 90/164
	Lane vehicle is travelling in 1 – Inner most lane (nearest to kerbside) 2/3/4 – According to the number of lanes for that location (the nearest to centre divider, the bigger the number)	Categorical	 56/85 47/103
Situational condition	*Stage of crossing* N – Near end (Stage 1) [reference] F – Far end (Stage 2)	Categorical	 52/116 52/72
	Direction of crossing T – Towards MRT[2] station F – From MRT station	Categorical	 69/114 35/74
	Type of junction X –Cross junction T – T-junction M – Mid-block crossing	Categorical	 4/21 80/119 20/48
Personal characteristics	*Gender* M – Male [reference] F – Female	Categorical	 82/129 22/59
	Target Type 1 Pedestrian w/o any walking hindrance Walking in pair Walking in group Pedestrian carrying bags Pedestrian on phone/music device Pedestrian with pram Pedestrian with child Pedestrian running Pedestrian with walking difficulty Normal cyclist Cyclist with child	Categorical	 68/112 3/3 11/32 1/14 3/7 0/1 0/1 8/1 2/4 8/13 0/0
	Target Type 2[3] Pedestrian alone Pedestrian accompanied Cyclist alone	Categorical	 82/138 14/37 8/13
	Average crossing speed (in m/s)	Continuous	-
	High risk crosser Y – Yes, used rolling gap N – No, did not use rolling gap	Categorical	 10/42 94/119

[1] *Available gap is the presented gap (in seconds) which was accepted or rejected by the subject.*
[2] *MRT: Mass rapid transit*
[3] *As many of the categories within the Target Type1 variable is having small or null counts, the variable is collapsed to Target Type 2 with fewer categories*

3.3 Methodology limitation

The current work is intentionally designed to examine pedestrian behaviour with respect to the existing scenarios. It did not include detailed vehicle dynamics such as the approaching speed and acceleration of vehicles, which will require larger extent of video footages. Also, the data were extracted from video footages, hence factors like trip purposes that are unobservable are not included.

4.0 Results and analysis

4.1 General observations

There were a total of 188 rejected gaps and 104 accepted gaps extracted from the video footages at the 7 locations. There were almost twice as many rejected gaps than accepted gaps because many of these violators were pre-green man violators. These people crossed after the last few vehicles of the last phase passed and as these violators crossed half way through the crossing, the pedestrian crossing lights turned to green which is the right of way for the pedestrians. No accepted gap was recorded in this case. Hence, there were fewer accepted gaps, compared to rejected gaps. Table 3 summarises the frequency, minimum, maximum, average and 85th percentile values of the observed rejected and accepted gaps. Two sample t-tests were done to compare the two methods (Methods 1 and 2) of calculating gaps and it was found that there are no significant differences (at 95% confidence level) for rejected gaps in all segments, and likewise for accepted gaps. Hence, the data were combined for Methods 1 and 2 subsequently.

During data extraction, it was observed that pedestrians sometimes do not wait for all the lanes to be completely clear before stepping onto the carriageway (First type). This typically occurs when the approaching vehicle is in the outer lane (relative to the pedestrian). The pedestrians anticipated that the lane would clear by the time they reached it and they used a partial gap (known as “rolling gap”) to cross the street (Brewer *et al.* 2005). In other words, there was a separate gap for each lane of traffic as the pedestrian proceeded across the street. Another type of rolling gap is that the pedestrian is still in the conflict area when the next vehicle arrives (Second type). Both behaviours are considered as high risk.

Table 3: Values of rejected and accepted gaps

Gap	Segment	Gap type	Count	Min	Max	Average	15th percentile	85th percentile
Rejected gaps	Near end 1	RNE1	95	0.6	15.3	4.2	1.6	6.4
	Near end 2	RNE2	21	0.0	9.4	2.9	0.6	5.2
	Far end 1	RFE1	52	0.5	6.1	3.0	1.3	4.8
	Far end 2	RFE2	20	0.2	12.2	3.3	0.7	6.7
Accepted gaps	Near end 1	ANE1	19	4.3	18.0	11.9	6.2	16.5
	Near end 2	ANE2	33	4.4	30.7	13.8	6.9	22.1
	Far end 1	AFE1	19	4.0	15.8	7.6	5.5	10.1
	Far end 2	AFE2	33	1.8	25.5	8.4	4.5	12.3

Table 4 summarises the number of cases adopting rolling gaps among the violators. About 22 per cent of the violators utilised the First type of rolling gaps while 10 per cent utilised the Second type.

Table 4: Proportion of high risk crossing behaviour (rolling gaps)

Crossing stage	Near End	Far End	Total
Vehicle still in conflict area when pedestrian stepped out (First type)	28	13	41
Total number of rejected gaps	116	72	188
Proportion	0.24	0.18	0.22
Pedestrian still in conflict area when vehicle reached (Second type)	3	7	10
Total number of accepted gaps	52	52	104
Proportion	0.06	0.13	0.10
First & second type	***31***	***20***	***51***
Same lane	5 (16%)	6 (30%)	11
Stopped by traffic light	6 (19%)	1 (5%)	7
Will be hit	12 (39%)	10 (50%)	22
Will not be hit	8 (26%)	3 (15%)	11

The mean accepted gap of the 17 (out of 41) cases of the First type of rolling gaps was 8.4 seconds which was shorter than that of the normal cases (10.5 seconds), and that of the 10 (out of 10) cases Second type was 3.3 seconds (compared to 11.6 seconds of the normal cases), confirming the riskier gap accepting behaviour. There were some (First type) rolling gap cases without next arriving vehicles that were hence excluded in the calculation.

During extraction, the travel lane of the last passing vehicle of all First type rolling gaps was observed. It is not unexpected to find that majority of the last passing vehicles (23/28 = 82% and 9/13 = 69% for near end and far end interactions, respectively) were at least one lane away from the pedestrians who utilised First type of rolling gaps.

Each case of rolling gap was further examined to determine if the pedestrian would have been hit if the vehicle were to change lane. 16% (near end) and 30% (far end) of the cases involved a vehicle travelling on the nearest adjacent lane to the pedestrian. 19% and 5% of the vehicles will be stopped by the traffic light phasing if they were to change lane from right-turning lane to straight through lane at the cross junctions. For the rest of the cases, there was a higher chance (12/20 = 60% at near end and 10/13 = 77% at far end) that the pedestrian will be hit if the vehicle were to change lane. Hence, this shows the riskiness of pedestrian adopting rolling gaps.

4.2 Distribution of gaps

The distributions and cumulative percentage of rejected and accepted gaps by crossing stage (near or far end) were plotted in Figures 3 and 4. The 85th percentile rejected gaps were 6.3 and 5.2 seconds for near end and far end crossing, respectively. In other words, the majority (85%) of the subjects rejected gaps that are 6.3 seconds or lesser at near end crossing, and 5.2 seconds or lesser at far end crossing. On the other hand, the 15th percentile accepted gaps showed that the majority of the subjects accepted gaps that were 6.4 and 5.2 seconds or greater for near end and far end crossing, respectively.

Two sample t-tests showed that the mean rejected gaps were significantly larger at near end than those at the far end at 95% confidence level. This is the same for mean accepted gaps (see Table 5). This suggested that the decision to accept gaps is more stringent (conservative) at the near end than at far end of the crossing. In other words, a person generally takes lower risk at the point when he/she decided to jaywalk (first stage of crossing) than when he/she was stuck at the centre divider (second stage of crossing).

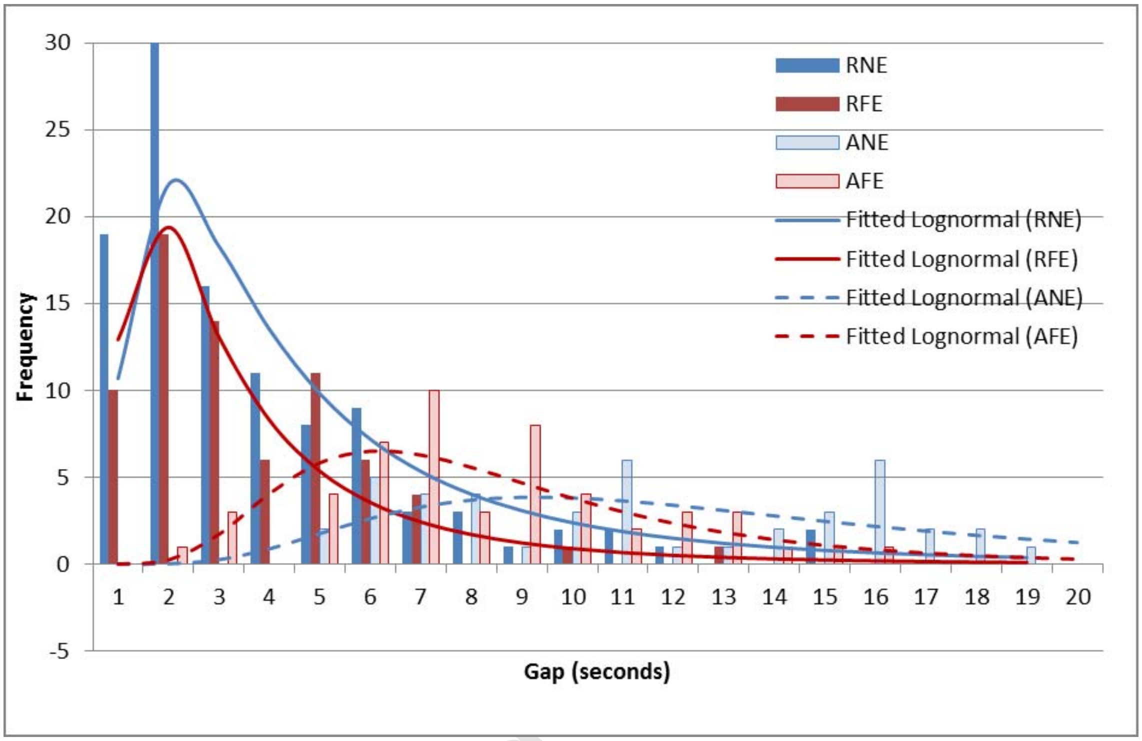


Figure 3: Distribution of rejected and accepted gaps

RNE: Rejected gap (near end); RFE: Rejected gap (far end); ANE: Accepted gap (near end); AFE: Accepted gap (far end)

Attempts were made to fit the observed gap rejection/acceptance with suitable statistical distributions. The log normal distribution was found to be the better fitting distribution for gap acceptance than normal distribution, using goodness of fit tests (p-values were greater than 0.05, fail to reject null hypothesis that it follows log normal distribution with p-values of 0.33, 0.58, 1.00 and 0.18 for RNE, RFE, ANE and AFE gaps, respectively). This finding is consistent with Wu et al. (2004).

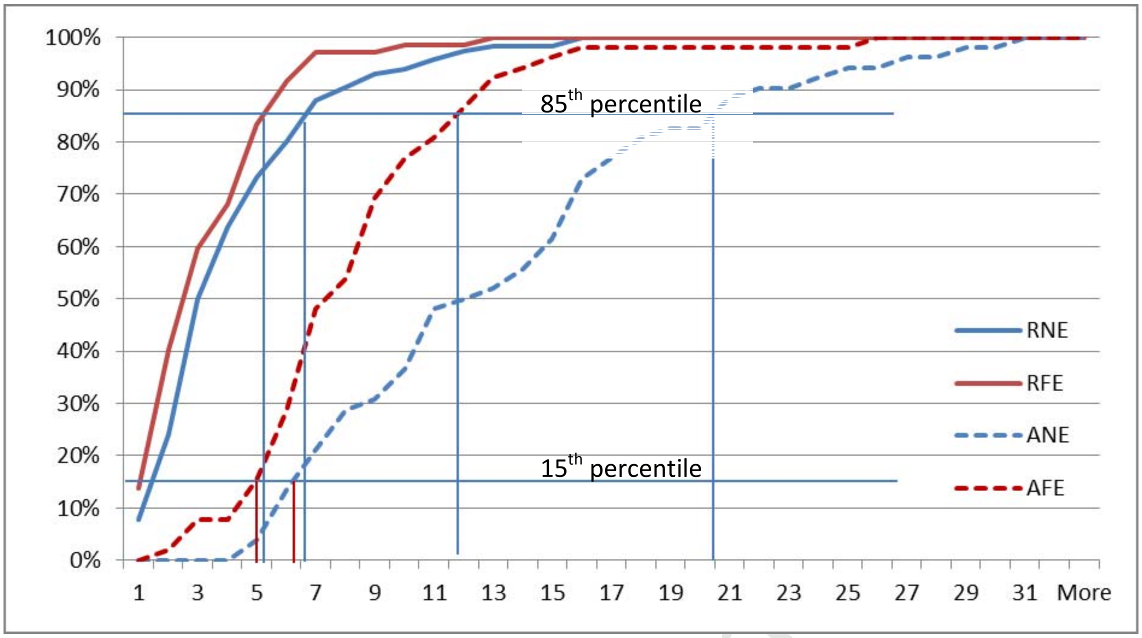


Figure 4: Cumulative percentage of rejected and accepted gaps

Table 5: Two sample t-tests between near-end and far-end gaps

Test	Mean (sample size)		t-stat (t-critical)	Significant
	Near-end	Far-end		
Rejected gaps	3.94 (116)	3.09 (72)	2.22 (1.97)	S
Accepted gaps	13.13 (52)	8.14 (52)	4.70 (1.99)	S

4.3 Modelling the decision to accept gap

Figure 5 shows the plot of proportion of pedestrians accepting gap at 1 second interval for both near end and far end crossings. A binary logistic regression was used to model the proportion of pedestrians accepting a gap, p, using the following equation:

$$p = \left(\frac{e^{\alpha+\beta x}}{1+e^{\alpha+\beta x}}\right)$$

where α=intercept and β=coefficient. Using SAS, logistic regression analysis was carried out where the dependent variable is the decision to accept or reject a gap at near end and far end and the independent variable is the gap (seconds). The α and β values for near end were found to be –3.24 and 0.31 while those for far end were –3.07 and 0.53, respectively (see Figure 6). This is interpreted as for every 1 second increase in the available time gap, a person is 1.4 (near end) and 1.7 (far end) times more likely to accept it. It was also found that a person waiting to make near end crossing had a wider indecision zone (gentler slope) than those waiting at the centre divider. The Hosmer and Lemeshow goodness of fit test showed that the models were nearly good fit. This suggests that the model could be improved by including more explanatory variables.

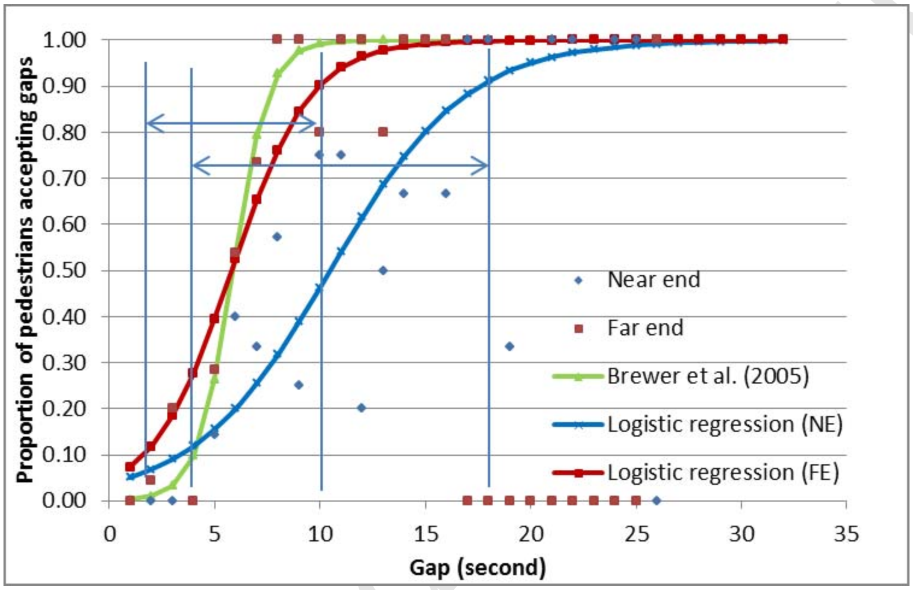


Figure 5: Proportion of pedestrians accepting gaps

The likelihood of accepting gaps was further modelled using the variables in Table 2. The univariate analysis showed that the independent variables gap, gap type, conflicting traffic type, stage of crossing, junction type, target type, crossing speed and high risk crosser have significant effects on the likelihood of accepting gaps individually (see Table 6).

Table 6: Results of univariate analysis

Variable (see Table 2 for definitions)	-2Log Likelihood			Likelihood Ratio Test $Pr>\chi^2$
	D_1 (without variable)	D_2 (with variable)	$G=D_1-D_2$	
Available gap	379.4	230.9	148.5	<0.0001
Gap Type	380.3	330.3	50.0	<0.0001
Vehicle Type	380.3	378.0	2.3	0.51
Conflicting traffic movement	380.3	374.0	6.3	0.04
Lane vehicle is travelling in	378.2	375.0	3.2	0.13
Stage of crossing	380.3	377.0	3.3	0.05
Direction of crossing	380.3	379.4	0.9	0.33
Type of junction	380.3	372.6	7.7	0.02
Gender	380.3	376.7	3.6	0.06
Target Type 1	380.3	357.3	1.9	0.01
Target Type 2	380.3	378.4	1.9	0.39
Average crossing speed	308.2	295.6	12.6	0.00
High risk crosser	355.0	343.3	11.7	0.00

The variable gap has the most significant effect, and was hence selected as the first variable to enter into the model. The other independent variables were put into the model one by one using stepwise selection method of PROC LOGISTIC in SAS (SAS 2012). Variable was added in the model provided the previous variable(s) did not become insignificant. The whole process stopped until no additional variable can enter the model. Through this process, the variables selected for the final model (see Table 7) were gap length, type of gap, stage of crossing and gender of subject; the probability of accepting gap was defined by the following equation:

$$p(Y=1) = \frac{e^{-3.21+0.57gap-2.23gaptype+2.02stage-1.77gender}}{1+e^{-3.21+0.57gap-2.23gaptype+2.02stage-1.77gender}}$$

From the Hosmer and Lemeshow, Deviance and Pearson goodness-of-fit tests, the final model was found to have a relatively good fit for the observed data as the chi-square (χ^2) statistic (8.67) was smaller than the critical value of a chi-square distribution (with p-values for $Pr>\chi^2$ not less than 0.05). From the table of 'association of predicted probabilities and observed responses' it was found that the percentage of concordant observations was 95.4

(close to 100), and the values of Somers' D (0.909), Gamma (0.910) and c (0.954) were close to 1. These statistics suggested that the model fitted the data very well.

Table 7: Results of the final logistic regression model (stepwise selection)

Variable	Class	Estimate	Std Error	Pr >χ^2
Intercept	Continuous	-3.21	0.65	<0.0001
gap	Continuous	0.57	0.08	<0.0001
gaptype	Method 1	-2.23	0.51	<0.0001
	Method 2 (reference)	-	-	-
stage	Far end	2.02	0.55	0.00
	Near end (reference)	-	-	-
gender	Female	-1.77	0.68	0.01
	Male (reference)	-	-	-

**n=218, Probability modelled is decision = Accepted*

Using Proc GLMSELECT (selection method=Least Angle Regression) in SAS, the variables selected for the final model were gap length, type of gap and stage of crossing. The R^2 and adjusted R^2 values of the model were 0.54 and 0.53, respectively. Using Proc Logistic to re-run the model (see Table 8), the percentage of concordant observations was 93.5 (close to 100), and the values of Somers' D (0.871), Gamma (0.872) and c (0.935) were close to 1. The model also performs relatively well without the additional variable gender. Hence, the second model is recommended.

Table 8: Results of the final logistic regression model (LAR selection)

Variable	Class	Estimate	Std Error	Pr >χ^2
Intercept	Continuous	-3.34	0.54	<0.0001
gap	Continuous	0.50	0.06	<0.0001
gaptype	Method 1	-1.76	0.38	<0.0001
	Method 2 (reference)	-	-	-
stage	Far end	1.52	0.41	0.00
	Near end (reference)	-	-	-

**n=291, Probability modelled is decision = Accepted*

In general, a positive parameter estimate for a continuous variable means that as X increases, the probability of accepting gap increases; for discrete variable, it means that maintenance at that particular level increases the likelihood of accepting gap as compared to the reference level.

As expected, a pedestrian was found to be more likely to accept a gap as the gap increases, when there is no last passing vehicle, and when he or she is performing Stage 2 crossing (Far end). The odds for a pedestrian to accept a gap when he or she was at the Far end crossing over the odds at Near end crossing was found to be 4.66 ($e^{1.54}$) (when all other variables are held constant). In terms of percent change, it is 366% higher. These situational and traffic characteristics are attributable to a riskier behaviour of a pedestrian at signalised pedestrian crossing.

5.0 Discussions and conclusions

From the extracted rejected and accepted gaps, longer gap acceptance (more conservative) was observed for the near end crossing (6.3 seconds) compared to the far end crossing (5.2 seconds). This could likely be due to the more cautious decision to violate the Red Man signal at the near end. In addition, if they had already chosen to violate, the second stage of crossing tended to be cleared faster (accepting shorter gap) as there is also another risk while standing at the centre divider. Another reason could be the fear of getting caught by police (for jaywalking) while waiting at the centre divider. Hence, it suggests that law making crossing during RM illegal may be, in some sense, harmful when it encourages such risky behaviour. From a motorist's perspective, one should pay extra attention and prepare to take evasive actions on pedestrians waiting at the centre divider, should they perform risky crossing behaviour.

About 20% of the violators were observed to utilise "rolling gaps", that is, they did not wait for all vehicles to clear the conflict area before they started to cross. Another 10% were still in the conflict area when the next vehicle arrived. These proportions of adopting "rolling gaps" were low compared to a US study which registered 60% adoption (Brewer *et al.* 2005). It should be noted that this study was conducted during 1h evening peak (less opportunity to adopt rolling gaps) compared to the US study which was conducted during peak/off-peak 4-h periods. These violators were the riskier ones and it was observed that majority of the last passing vehicles were at least one lane away from the pedestrian when "rolling gap" was adopted. A further analysis on whether the pedestrian will be hit if the vehicle were to change lane showed that there is a high chance (60% at near end crossing and 77% at far end crossing) of this happening. Hence, it is advisable for pedestrians not to utilise rolling gaps.

Logistic regression was used to model the probability of a pedestrian accepting gap and suggest predictors. A model with relatively good fit was found with available gap length, gap type, and stage of crossing. Pedestrians who are exposed to longer available gap are more likely to accept the gap. Pedestrians who are exposed to Type 2 gap (without last passing vehicle) are most likely to accept the gap. From an approaching motorist's perspective, if there is no other vehicle ahead, one has to expect a greater likelihood for the pedestrian to jaywalk. When exposed to the same gap length, a pedestrian has greater odds to accept the gap at Far end compared to Near end. Visibility of the pedestrian at centre divider should be further enhanced (to allow motorist to notice his/her presence) to improve safety for pedestrians. The finding is useful to alert motorists of the type and occurrence of potential riskier pedestrian (accepting short gaps) in the pedestrian stream, hence reducing chances of conflicts or accidents.

The current work collected observational pedestrian behaviour data from video footages on gap acceptance. It allows greater understanding of the pedestrians' behaviour at the crossings. It will also be beneficial for modellers to use this collected data in simulation to mimic more realistic pedestrian behaviour at signalised pedestrian crossings. The microsimulation models could then allow practitioners to evaluate the effects of certain improvements at these crossings more accurately.

In addition, there are some policy implications arising from some of the results from the study. Enhancing pedestrian safety should be targeted through educational and public awareness campaigns to deter them from engaging in risky behaviour and to promote safe crossing behaviour.

In future research, it may be worthwhile to complement video analysis with a perception survey on violators to include other personal factors like marital status, age, number of children, availability of private vehicle, familiarity with the crossing and accident history (Hamed 2001).

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Highlights:

Gap acceptance at signalised pedestrian crossings > longer accepted gaps at near end of crossings compared to far end of crossings > 20% of violators adopted partial gaps > gap, gap type, stage of crossing and crossing speed affect gap acceptance