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Gap acceptance of violators at signalised pedestrian crossings

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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.

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1. 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 (SGM), followed by the Flashing Green Man (FGM) and the Red Man (RM). 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 flash 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 (GM=SGM+FGM). (It is useful to note that Singapore is a left hand

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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. 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 s, 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 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 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).

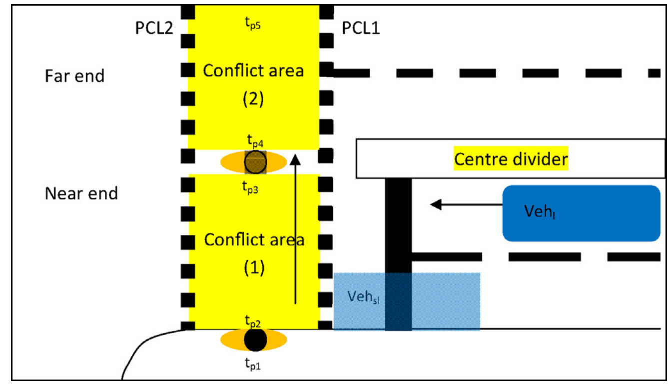

Fig. 1. Schematic diagram of gap acceptance. Veh_l: Last passing vehicle, Veh_{sl}: Second last passing vehicle; PCL1: pedestrian crossing line 1; PCL2: pedestrian crossing line 2.

3. 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 to 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 and 7pm) with at least one hour of uninterrupted recording for each location.

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 s 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 Fig. 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 Fig. 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

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