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Roles of personal and environmental factors in the red light running propensity of pedestrian: Case study at the urban crosswalks

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ABSTRACT

Pedestrian is vulnerable to mortality and severe injury in road crashes. Red light running violation of pedestrians is one of the leading causes to the crashes at signalized intersections, at which the crash involvement rates of pedestrians are high. Therefore, it is important to identify the factors that affect the propensity of red light running of pedestrian. In this study, effects of both personal factors (pedestrians' demographics and behavior) and environmental factors (presence and behavior of other pedestrians, signal time, and traffic condition) on the individual decision of red light running violation are examined, using the video observation surveys at the signalized crossings that are prone to pedestrian-vehicle crashes and have moderate pedestrian and vehicular traffic volumes in the urban area. Crossing behaviors of 6320 pedestrians are captured. Results of a random parameter logit model indicate that pedestrian gender, age, number of lanes, presence of a companion, number of pedestrians around, presence of other violators in the same cycle, time to green, red time, traffic volume, and percentage of heavy vehicles all affect the propensity of red light running violation of pedestrians. Also, there are significant interaction effects by pedestrian's gender and age, presence of other violators, with a companion, and traffic volume on the propensity. Findings are indicative to the development of effective engineering, enforcement and educational initiatives combating the red light running violation behavior of pedestrians. Therefore, pedestrian safety level at the signalized intersections can be enhanced.

Keywords: Red light running violation; pedestrian safety; signalized intersection; observation survey; random parameter logit model

1. INTRODUCTION

Walking is increasingly promoted as a sustainable transport mode. Hong Kong Transport Department has been undertaking various policy initiatives to enhance the walkability of Hong Kong. Safety is one of the important attributes of walkability. For instance, Speck (2013) has defined four assessment criteria of walkability: usefulness, comfort, attractiveness and safety. However, pedestrians are vulnerable to fatality and severe injury in road crashes (World Health Organization, 2018). In Hong Kong, 62% of road fatalities are pedestrian. For instance, non-compliance with traffic signals of pedestrians is the leading cause of pedestrian crashes. It constitutes about 25% of pedestrian crashes at the signalized intersections (Transport Department, 2017). Therefore, it is of high importance to identify the factors that affect the occurrence of red-light running violations of pedestrians, particularly at the locations that are prone to vehicle-pedestrian conflicts and associated crashes. Then, effective engineering, enforcement and educational initiatives can be developed to deter against red light running violations.

Factors affecting the propensity of traffic violation and road crash are usually categorized into three types: human, traffic and road environment. Human factors refer to the demographics and socioeconomic characteristics of an individual. For the traffic condition, effects of traffic volume, vehicular speed and traffic composition are considered. Likewise, the road environment is characterized by the factors including geometric design, pavement condition, lighting condition and traffic control. In the conventional studies, discrete choice approaches (i.e. binary logit and probit) are applied to examine the effects of explanatory factors on the individual decision of red light running violation (Kim et al., 2008; Rosenbloom, 2009; Brosseau et al., 2013; Koh et al., 2014; Russo et al.,2018; Zhang et al.,2018; Wang et al., 2019). The propensities of illegal behavior are different among the pedestrians who have the same demographics and socioeconomic characteristics. For example, adolescents tend to be more risk-taking, and are more likely to commit red light running violation offence. However, the propensities even of the same person could be lower under adverse weather condition. Effect of the latter is often not measured. To control for the effect of unobserved heterogeneity on the individual decision, random parameter logit or probit model can be applied (Xie et al., 2017). On the other hand, behaviors of the pedestrians arriving at the signal crosswalk in the same cycle tend to be similar. Red light running propensities of the pedestrians in the same cycle are more likely affected by the environmental factors including road environment, pedestrian volume, traffic condition and signal time. To this end, linear modeling approaches can be applied to evaluate the effects of traffic and road environment attributes on the red light running violation rate of pedestrians in the same cycle (Diependaele, 2018).

However, it is rare that the roles of personal (individual level) factors of pedestrian and environmental (cycle level) factors in the prevalence of red light running behavior of pedestrian are investigated. Particularly, to the best of our knowledge, not many studies have considered the effects of the behaviors of other pedestrians when evaluating the propensity of red light running. Additionally, the interaction effects between personal characteristics, social influences, and environmental features on the propensity of red light running violation have not been revealed. In this study, we aim to identify the factors including personal characteristics of pedestrian, behaviors of other pedestrians, traffic condition, signal time and road environment that affect the decision of red light running violation of pedestrian based on the video observation survey in the urban area of Hong Kong. Both the individual level (pedestrian demographics and behavioral attributes) and cycle level (pedestrian arrival pattern, traffic volume, traffic composition and signal time plan) factors are incorporated into the same model.

In Hong Kong, a typical pedestrian signal cycle has three phases: steady green signal; flashing green signal; and steady red signal. It is illegal for a pedestrian to cross during the steady red time, and to start crossing during the flashing green time. There is no pedestrian signal countdown display at the pedestrian crosswalks in Hong Kong. In this study, crossing behaviors of 6320 pedestrians during the red (pedestrian) signal at six signalized crosswalks in both the peak and non-peak periods of the daytime are captured. Then, a random parameter logit model is developed to measure the association between the propensity of red light running violation and possible explanatory factors. Moreover, effects of social influences as indicated by the presence, number and behaviors of other pedestrians around on the red light running propensity are considered. Results should be indicative to the development of future policy initiatives that can combat the red light running behavior of pedestrians, and therefore, reduce the pedestrian crash and injury risk.

Remainder of this paper is organized as follows. Section 2 reviews the literatures on the red light running behavior of pedestrians. Study design, method of data collection and model formulation are described in Section 3. Section 4 and Section 5 presents the analysis results and policy implications respectively. Finally, concluding remarks and future research directions are summarized in Section 6.

2. LITERATURE REVIEW

2.1 Factors affecting the red light running behavior of pedestrians

2.1.1. Demographics and socioeconomic characteristics of pedestrian

For the demographics, majority of studies indicated that propensity of red light running of male pedestrians was higher than that of females (Rosenbloom, 2009; Guo et al.,2011; Xie et al., 2017). However, the gender effect on red light running violation depends on the traffic condition. Propensity of red light running of female pedestrians could be higher when the available gap time of approaching traffic increases (Ren et al., 2011). Yet, a national survey indicated that no evidence could be established for remarkable difference in red light running propensity between male and female pedestrians (Dommes et al., 2015). For the age effect, studies indicate that crossing behaviors of older pedestrians are different from that of the younger counterpart (Gorrini et al., 2016, 2018). For example, propensities of red light running of the former tend to be lower (Kim et al., 2008; Wang et al., 2011). Older pedestrians are more willing to wait at the crosswalks and obey the traffic rules (Guo et al., 2011; Diependaele, 2018; Zhang et al., 2018). However, risk of mortality and severe injury in the road crashes of older pedestrians are remarkably higher than that of normal adults (Asher et al., 2012). It is attributed to the reduction of locomotion (Oxley et al., 1997, Winogrond, 1981) and degradation of perception and cognitive skills by age (Dommes et al., 2013).

For the socioeconomic characteristics, Wu et al. (2014)'s study indicates that the educational background of pedestrian can affect the crossing behavior. An attitudinal model indicates that both the education level and income of a pedestrian can affect the red light running propensity (Zhang et al., 2016). However, it is rare that the roles of personal factors in pedestrian's crossing decision under different environmental conditions are examined. Indeed, the attitudinal survey that focuses on the contributions of personal factors to the safety awareness and pedestrian decision should have considered the effects of traffic condition and road environment factors.

2.1.2 Traffic control and road environments

For the effect of traffic control, presence of an exclusive pedestrian signal (Cambon de Lavalette et al., 2009) and the pedestrian signal countdown (countdown to green) device (Markowitz et al., 2006) are negatively correlated with the red light running frequency. On the other hand, increase in (maximum) waiting time is correlated with the increase in red light running rate of pedestrians at the midblock crosswalks (Van Houten et al., 2007; Brosseau et al., 2013).

For the effect of geometric design, both the number of traffic lanes and length of pedestrian crossing affect the red light running rate of pedestrians. For instance, increases in the number of traffic lane and crosswalk length are correlated with the reduction of red light running violation rate (Van Houten et al., 2007; Cambon de Lavalette et al., 2009; Diependaele, 2018). Additionally, other geometric design and traffic attributes, including the presence of central refugee (Cambon de Lavalette et al., 2009; Yan et al.,2016), speed of approaching vehicle (Lobjois et al., 2013; Sun et al., 2015), volume of conflicting vehicle stream (Koh et al., 2014; Wang et al., 2011), available gap time (Koh and Wong, 2014) can all affect the red light running violation rate of pedestrians. For instance, increases in the volume of conflicting vehicle stream and speed of approaching vehicle are correlated with the reduction of red light running rate.

The abovementioned studies focus on the effects of environmental factors at the intersection level (micro-level). Indeed, environmental factors including land use, weather and lighting condition at the macro-level can also affect the red light running propensity of pedestrians. Guo et al. (2011) conducted an observation survey to examine the effect of land use, e.g., commercial, industrial and residential, on the red light running propensity of pedestrians. Results indicated that the red light running rate was lower at the crosswalks near the schools. Weather, lighting condition and visibility also affect the red light running frequency of pedestrians. Li and Fernie (2010) indicated that the pedestrian walking speed and red light running rate under the cold and snowy conditions were higher than that under the warm weather and when the pavement surface was dry. Liu and Tung (2014) indicated that the pedestrian could be more cautious and have a lower propensity of red light running when crossing under the dark and poor visibility conditions. Yet, it is necessary to examine the interaction effects by pedestrian demographics and socioeconomic characteristics on the association between road environment, traffic control and red light running propensity.

2.1.3 Social influences and presence of other pedestrians

Presence and behaviors of other pedestrians can affect the red light running propensity of an individual. It is attributed to the effect of social norms. Faria et al. (2010) suggests that pedestrians tend to follow the behaviors of others for the traffic gap judgment. This is the possible cause of unsafe crossing behavior. Pedestrians tend to be more inattentive when they are alone, as compared to being part of a large group. Studies also indicate that red light running propensity decreases when number of other pedestrians (crossing or waiting) around increases (Rosenbloom, 2009; Russo et al., 2018; Zhang et al., 2018). Furthermore, Rosenbloom (2009) suggested that pedestrian age could modify the association between red light running propensity and number of pedestrians around. For example, adolescents are more risk-taking. Such risk-taking behavior is more prevalent when the pedestrian group size increases. On the other hand, study also suggests that female pedestrians are more sensitive to the effect of social norms (Sorenson and Taylor, 2005). Therefore, it is worth exploring the interactions between (presence and size of) pedestrian group, demographics and red light running propensity of pedestrians.

To sum up, studies had revealed the effects of personal characteristics, traffic attributes and road environments on the red light running propensity of pedestrian in the separated models. Some focus on the effects of personal factors on individual decision, while others focus on the effects of traffic and road environment factors on the overall red light running violation rates. However, it is rare that the roles of personal and environmental factors in the individual decision of red light running violation are examined. Additionally, it is necessary to investigate the interactions between the individual level (pedestrian demographics, socioeconomic characteristics and pedestrian behavior) and cycle level (traffic condition, road environment and signal time) factors on the propensity of red light running. Moreover, intervention by the social influences of the presence and behavior of other pedestrians on the propensity should be examined.

2.2 Methodological issues

From the methodological perspective, single factor and multi-factor analysis of variance (ANOVA) approach can be applied to compare the crossing behavior of different pedestrian groups (Li and

Ferinie, 2010, Ren, et al., 2011). Alternately, it is possible to model the pedestrian crossing behavior by estimating the expected time duration until the occurrence of an ‘event’, i.e. red light running violation, using survival analysis (Hamed, 2001; Tiwari et al., 2007). In addition, as pedestrians do not necessarily wait until there is no traffic on every lane, a rolling gap approach has been proposed to model the gap acceptance behavior, and thus the red light running propensity of pedestrians (Koh et al., 2014). Furthermore, to model the effects of real-time traffic flow, signal time, and pedestrian position and motion on the crossing decision, a probabilistic approach - Dynamic Bayesian Network model has been proposed (Hashimoto et al., 2016). To model the red light running propensity of pedestrians while the confounding effects of all possible factors are considered, regression models for dichotomous data including binary logit and probit models are commonly used (Kim et al., 2008; Rosenbloom, 2009; Brosseau et al., 2013). To account for unobserved heterogeneity in pedestrian crossing decision, the random parameter approach should be applied (Wang et al., 2019; Bai and Sze, 2020).

3. METHOD

3.1. Video observation survey

To capture the information on the crossing behavior, pedestrian personal factor, traffic attributes, road environments and signal time plan, the video observation surveys were conducted at six signalized crosswalks in the urban area of Hong Kong on the weekdays. The sites under investigation were all hot spots of pedestrian crashes (each had more than ten pedestrian crashes in the preceding five years). About half of the crashes involving pedestrians occurred when the pedestrian signals were ‘steady red’. This implies the red light running behaviors of pedestrians could be of great concern. At each site, the duration of observation was five hours (2 hours in the morning and 3 hours in the afternoon). The weather, lighting, visibility and pavement surface conditions were fine during the survey.

Figure 1 and **Table 1** present the locations and characteristics of the six sites under investigation. The pedestrian and vehicular traffic volumes were high during the survey. Additionally, one should note that the cycle time and green time of all intersections in Hong Kong are not fixed. The signal time plans are responsive to the real-time traffic volume.

<Insert Table 1>

<Insert Figure 1>

3.2. Method of data collection

Figure 2 illustrates the sequence of pedestrian signals. As shown in Figure 2, there are three different (pedestrian signal) phases in a cycle: (i) green – pedestrians can cross; (ii) flash green – pedestrians can cross but cannot start to cross; and (iii) red – pedestrians cannot cross. In this study, we focus on the red light running decision of pedestrians arriving during red (pedestrian) time. In particular, effects of pedestrian demographics, other characteristics and behavior of other pedestrians, signal time and traffic condition on the red light running propensity of pedestrians will be examined. For the pedestrian demographics, effects of gender and age (adolescent, adult and elderly) are investigated. Also, other attributes including presence of baggage, presence of children, presence of a companion are considered. Number and behaviors (violated red signal or not) of other pedestrians in the same cycle indicate the effects of social norms on individual decision. It is expected that a pedestrian who is accompanied by a friend or family member may have a lower tendency to run the red light. Also, the propensity of red light running may be lower when there are more pedestrians (not run the red light) around. However, the propensity of red light running might be higher when other pedestrians violated the red signal. For the signal time attributes, factors considered are cycle time, green time and time to green (upon the arrival of a pedestrian). It is expected that the propensity of red light running would increase when time to green (maximum waiting time) increases. For the traffic condition, effects of pedestrian arrival rate, vehicular traffic volume, average available gap time and percentage of heavy vehicles are considered.

Figure 3 provides an illustration for the estimation of pedestrian waiting time as well as time to green. As shown in Figure 3, pedestrian waiting time refers to the difference between (pedestrian) arrival time and entry time (start to cross). Time to green refers to the difference between (pedestrian) arrival time and the start of green. In this study, we focus on the decision of pedestrians arrived during the red time. Pedestrians of concern (who violate pedestrian red signal) are shaded in solid red in Figure 3.

<Insert Figure 3>

In the survey, characteristics and behavior of 6,320 pedestrians which arrived at the six crosswalks under investigation during the red time of 652 cycles are recorded. **Table 3** summarizes the characteristics of the 6,320 pedestrians. Of the 6,320 pedestrians, 1,169 (18.5%) ran the red light. For the cycle level factors, pedestrian and vehicular traffic attributes in 652 cycles were captured. As shown in Table 3, the average cycle time is 151.8 seconds and the average red time is 72.5 seconds respectively. Also, variations in pedestrian and vehicular traffic volumes of the sample are considerable.

<Insert Table 2>

3.3 Analysis Method

Outcome variable of this study is dichotomous (run the red light versus not run), therefore, the binary logit regression approach is used to measure the association between pedestrian decision of red light running and possible risk factors. To account for the unobserved heterogeneity effect on the association, the random parameter approach will be applied (Hensher and Greene, 2003). For instance, effects of the variation in risk-taking behavior, safety perception and attitude towards red light running violation enforcement, which are often not observed and measured, on the decision among the pedestrians of the same demographics and socioeconomic characteristics can be accommodated. Formulation of the proposed random parameter logit model is given as follows.

Y_i=1 denotes that the i^{th} pedestrian violates the red light, and Y_i=0 the otherwise. Suppose the probability of Y= 1 is p and that of Y = 0 is 1−p respectively, then we have,

$$y \sim Binomial(p)$$

$$\log it(p) = \log(\frac{p}{1-p}) = \mathbf{X}_i\boldsymbol{\beta} + \varepsilon_i \tag{1}$$

where $\mathbf{X}_i$ is the vector of explanatory variables, $\boldsymbol{\beta}$ is the vector of corresponding coefficients (i.e., $\beta_1, \beta_2, \ldots, \beta_l$) and ε_i is the identically and independently distributed random error term respectively.

One restriction of Equation (1) is that it assumes the effects of individual explanatory variables to be fixed across observations. This ignores the effect of unobserved heterogeneity (i.e., personality and attitude) on the association between red light running violation propensity and pedestrian characteristics. To account for the effect of unobserved heterogeneity, the coefficients are assumed to be randomly distributed with the formulation given as follows,

$$\beta_{il} = \beta_l + \varphi_i \tag{2}$$

where φ_i is normally distributed with a mean of zero and variance of σ^2.

Then, a random parameter model is established based on the conditional probability specified as follows,

$$PROB\left[y_i = 1 \middle| x_i, \beta_i\right] = F\left(\beta_i ' x_i\right) \tag{3}$$

Parameter estimation of the proposed random parameter logit model is carried out using the maximum likelihood approach with the NLOGIT (Version 5.0) software (Greene, 2012). The parameters are assumed to be normally distributed (Christoforou et al., 2010; Milton et al., 2008). Additionally, a stepwise iterative approach is applied to evaluate whether a parameter is random or not (see Islam and Jones, 2014; Zhai et al., 2019).

To assess the prediction performance of candidate models, the Akaike Information Criterion (AIC) is used. AIC takes into account both the model fit and model complexity. AIC is specified as follows,

$$AIC = -2\ln(L) + 2K \tag{4}$$

where L refers to the maximum likelihood function and K refers to the number of parameters respectively.

4. RESULTS

In this study, both the models with and without considering the possible interaction effects (between personal and environmental factors) were developed. Prior to the association measure, a multi-collinearity test was carried out to ensure that the variables included were not highly correlated. In particular, results of multi-collinearity test indicate that there is a remarkable correlation between time to green and waiting time, therefore, only the ‘time to green’ is included in the confined model. No evidence can be established for possible multi-collinearity for other factors of concern.

4.1 Model 1 (with no interaction effect)

Table 3 presents the parameter estimation results. Table 3 (Model 1) illustrates the results of model with no interaction effect. Taking into account the possible confounding factors, some factors including presence of baggage, presence of children and pedestrian arrival rate are included in the proposed model, even they are not statistically significant.

For the pedestrian demographics, gender significantly affects the propensity of red light running at the 1% level. For instance, propensity of red light running of female pedestrians is lower (β = -0.405, *odds ratio* = 0.667) than that of males. Pedestrian age group is correlated with the propensity of red light running at the 5% level of significance. For example, adolescents have the lower propensity (β = -0.181, *odds ratio* =0.834) and older pedestrians (β = 0.189, *odds ratio* = 1.208) have the higher propensity, as compared to normal adults.

For the effect of other pedestrians, presence of a companion is correlated with the reduction in red light running violation propensity at the 1% level (β = -0.546, *odds ratio* = 0.579). Also, increase in the number of pedestrians around is correlated with the reduction in red light running propensity at the 1% level (β = -0.379, *odds ratio* = *0*.685). In addition, presence of other pedestrians' violation is correlated with the increase in the propensity at the 1% level (β = 1.392, *odds ratio* = 4.023). However, no evidence can be established for the association between presence of baggage, children and red light running violation.

For the signal time, increase in time to green (β = 0.072) and red time (β = 0.061) are significantly correlated with the increase in red light running propensity at the 5% level. For the traffic condition, increase in traffic volume (β = -0.025) and the percentage of heavy vehicles (β = -0.016) are correlated with the reduction in the propensity of red light running at the 5% and 1% level respectively. Additionally, increase in the number of lanes is significantly correlated with the decrease in the propensity of red light running at the 1% level (β = -0.803).

4.2. Model 2 (with interaction effects)

To examine the interactions between personal and environmental factors, and their interventions on the association between red light running propensity and possible factors, interaction terms (i.e. "gender x traffic volume", "gender x other pedestrians violated red light", "elderly x with a companion", "elderly x other pedestrians violated red light" and "other pedestrians violated red light x with a companion") are added. **Table 3** also shows the results of parameter estimation of the model with interaction terms (Model 2). As shown in Table 3, performance of model with interaction terms (Model 2) is superior to that with no interaction (Model 1). Results of parameter estimations among Model 1 and Model 2 are similar except that there are interaction terms in the latter.

As also shown in Table 3 (Model 2), interaction effects between gender and traffic volume (β = -0.021) and between gender and violation of other pedestrians (β = 0.515, *odds ratio* = 1.674), on the propensity of red light running are significant at the 1% level. Also, interaction effects between elderly and presence of a companion (β = -0.221, *odds ratio* = 0.802) is significant at the 5% level and that between elderly and violation of other pedestrians (β = 1.126, *odds ratio* = 3.083) is marginal at the 10% level respectively. Additionally, interaction effect between violation of other pedestrians and presence of a companion (β = 0.996, *odds ratio* = 2.707), on the propensity of red light running violation, is significant at the 1% level.

<Insert Table 3>

5. DISCUSSION

In this study, the roles of pedestrian personal factors, social influences (presence of companion, presence and number of other pedestrians, and violation of other pedestrians), and environmental factors in the individual decision of red light running violation are examined. Also, the possible interaction effects by pedestrian demographics, signal time and traffic condition on the propensity are considered. To measure the sensitivity of the red light running propensity, the marginal effects (i.e. percentage change in propensity in response to per unit change of explanatory variable) are also estimated. Discussions mainly focus on the model with interaction terms included (which has better model fit).

5.1 Effects of the presence and behaviors of other pedestrians

Presence of a companion and increase in the number of pedestrians around both reduce the red light running propensity of pedestrians with the elasticities of -0.228 and -0.942 respectively. More specifically, probability of red light running reduces by 0.94% when the number of pedestrians around increases by 1%. This finding is consistent with that of previous studies. Such phenomenon can be attributed to the influence of social norms (Rosenbloom, 2009; Zhang et al., 2016; Russo et al., 2018). Yet, effect of the number of pedestrians around on the individual decision varies remarkably. It is possible that the effects of pedestrian gender and age are sensitive to the social norms (Sorenson and Taylor, 2005).

Additionally, red light running propensity increased when at least one other pedestrian violated the red light. This implies that other pedestrians would be motivated (e.g. encouraged to violate the traffic rules) after the first violator appeared. Such phenomenon can be attributed to the vicarious experience of punishment avoidance in accordance to the deterrence theory (Ellis, 2003). Moreover, presence of a companion could interact with the association between propensity and behaviors (red light running violation) of other pedestrians. This suggested that pedestrians who had a companion could be even more motivated (by the traffic violation of other pedestrians), as compared to the pedestrians who were alone. However, information on the safety perception and attitude of pedestrians are not available in the current observation survey. It is worth exploring the trade-off between the perceived benefit (e.g. time saving) and anticipated cost (e.g. higher crash and injury risk) of the pedestrians when making the crossing decision, when more comprehensive data on the demographics, socioeconomics, safety perception and anticipated crossing behavior are available in the questionnaire survey. Moreover, since the presence of the first violator could have an adverse impact on the red light propensity of other pedestrians, increases in the certainty (i.e. enforcement level) and severity (i.e. penalty level) of penalties may be of essence to deter against the red light running violation of pedestrians (Chen et al., 2020).

5.2 Effects of personal factors

Results indicate that propensity of red light running violation of female pedestrians is lower. For instance, given that the parameter of gender is normally distributed, the chance that the propensity of red light running of females is lower than that of males is 64.3%. This finding is consistent with that of previous studies (Rosenbloom, 2009; Xie et al.,2017; Guo et al., 2011). Indeed, involvement rate of fatal crash of female pedestrians is lower than that of males (Harre et al., 1996). Additionally, the random component of gender effect is statistically significant at the 1% level. This justifies that the risk-taking attitude and safety awareness could vary remarkably among female pedestrians. Interestingly, the interaction effects by the traffic volume and presence of violation behavior of others on the association between gender and red light running violation propensity is significant. It implies that the social influences (particularly for the leading behavior of other pedestrians) and traffic condition can moderate the safety perception and therefore the crossing behavior of female pedestrians. Yet, it is worth exploring the reasons for such modifications on the individual decision, if more comprehensive data on the safety awareness of pedestrian is available in the perceptional survey (Ren et al., 2011).

For the age effect, adolescent pedestrians have a lower tendency to run the red light, as compared with normal adults. Indeed, it is rare that difference in the red light running propensities between adolescent pedestrians and normal adults is attempted. As revealed in this study, adolescents generally well behave. It could be because adolescents generally have better safety perception and cognitive capability (Evans and Norman, 2003). Also, adolescents could have better sense of law compliance with traffic rules because of the education (Lee et al., 2004). Results also indicate that older pedestrian has a high tendency to run the red light. This finding is contradictory to that of some previous works (Rosenbloom, 2009; Jiang et al., 2011; Wang et al., 2019), but consistent with that of a Chinese study (Cao et al., 2017). An earlier study in Hong Kong suggested that no evidence could be established for the relationship between age and red light running violation (Xie et al., 2017). However, as revealed in the police crash investigation record, 58% of pedestrians killed in road crash were of age above 65 years. Also, the main contributory factors to the crash involvement of older pedestrians were ignorance of pedestrian signal and reckless crossing (Transport Department, 2018). This is consistent with the finding of a previous study that risk of fatality of older pedestrians in the road crashes is significantly higher than that of normal adults (Asher et al.,2012). There are two possible reasons. First, obedience is positively associated with the education level (Bray and Lee, 1993; Zhang et al., 2016). Generally, older peoples in Hong Kong have relatively low educational attainment. Second, older peoples tend to have poor cognitive abilities. They may not be able to response to the hazard situations appropriately (Dommes et al., 2013). Yet, results also indicate that red light running propensity of older pedestrians increases when other pedestrians violate and decreases when they have a companion. This could be because older pedestrians may have poor judgment and tend to follow others' behavior. Also, the companion of an elderly (probably caretaker) tends to comply with the traffic rules. Yet, it is worth exploring the effects of leading violation behavior on the safety perception of pedestrians (particularly for the pedestrian groups that have lower self-identity) when more comprehensive information is available in the experimental or attitudinal models. Nevertheless, higher propensity of red light running violation of older pedestrian is an alarming issue. Same as other modern societies, Hong Kong is facing the problem of ageing population. Proportion of population older than 65 years is expected to increase from 16% in 2016 to over 25% in 2035. Elderly populations are concentrated in the early developed urban areas, which have frequent pedestrian activities and conflicts between pedestrian and vehicular traffic. More importantly, over 30% of pedestrian casualties are elderly (1,064 in year 2017) in Hong Kong (Transport Department, 2018). Therefore, it is important to develop effective enforcement, educational and publicity initiatives that can improve the safety awareness and combat the red light running violation behavior of older pedestrians (Harkey and Zegeer, 2004).

5.3 Effects of signal time and traffic condition

Propensity of red light running violation of pedestrian increases with the increase in time to green as well as the red time. It is because pedestrians tend to be annoyed and impatient when the anticipated waiting time increases. Such phenomenon occurred when the pedestrian signal countdown device was present as revealed in the previous study (Brosseau et al., 2013). However, there is no pedestrian signal countdown device in Hong Kong. It is suspected that the pedestrians can have good estimate of anticipated waiting time by observing the surrounding environment (i.e. number of pedestrians around and signal phases of other traffic streams), even if the signal countdown device is absent. It is suggested that the signal time (green time for pedestrian) should be responsive to both the pedestrian and vehicular traffic volumes. It is indeed viable since reliable pedestrian tracking technology is now readily available in the market. On the other hand, whether the application of pedestrian signal countdown (countdown to green) could be effective in improving the perception of pedestrian, and therefore, combating the red light running behavior deserves further investigation. Nevertheless, safety perception towards pedestrian signal countdown can be gauged using an attitudinal model in the extended study.

For the effect of traffic condition, propensity of red light running rate is lower when the traffic volume and percentage of heavy vehicles increase (with the elasticity of -0.518 and -0.484 respectively). This is consistent to the findings of previous studies (Koh et al., 2014; Wang et al., 2011; Koh and Wong, 2014). This implies that the pedestrian decision is sensitive to both the approaching vehicles as well as the vehicle class (heavy vehicle), which the likelihood of more severe injury may increase when heavy vehicles are involved. Propensity will be reduced by 0.48% and 0.52% when the percentage of heavy vehicles and traffic volume increase by 1%. The propensity may vary with the gender and age of pedestrians. For instance, females are more sensitive to the traffic volume, as compared to males. However, vehicular speed, which is correlated with the risk and severity of possible crash, is not measured in this study. In the extended research, it is worth exploring the interactions between vehicular speed, pedestrian characteristics and the decision of red light running violation, when the comprehensive information on the traffic flow attributes (i.e. flow, density and speed) is available. Nevertheless, similar surveys can be carried out at the crosswalks of varying speed limits. Regardless of the above, warning signs indicating the prevalence of heavy vehicles and high traffic volume may be effective in improving the safety awareness and deterring against red light running violation of pedestrians.

6. CONCLUSION

Red light running behavior of pedestrians is a significant contributory factor to pedestrian crashes, in which the pedestrians are more vulnerable to mortality and severe injury than the car occupants. This study aims to examine both the personal (gender, age, pedestrian behavior) and environmental (signal time and traffic condition) factors affecting the individual decision of red light running violation using the video observation survey at the hot spots of pedestrian crashes. Also, effects of the presence and behavior of other pedestrians in the same cycle on the propensity are considered. Moreover, interaction effects by personal and environmental factors on the propensity are considered. Contribution of this study is of two-fold. Firstly, both the individual-level (personal demographics and behavior) and cycle-level (traffic condition and signal time) factors are included in the analysis of individual decision of red light running violation. Secondly, influence of social norms (presence of a companion, number of pedestrians around and violation of other pedestrians) on the individual decision is examined.

For the personal factors, it is known that female pedestrians generally have lower propensity of red light running, compared with males. This study reveals that presence of a violator and traffic volume can moderate the association between gender and propensity of red light running. For example, propensity of red light running of female pedestrians increases when other pedestrians violate the red light. Also, propensity of red light running of female pedestrians reduce when the traffic volume is high. On the other hand, previous studies suggested older pedestrians were risk-averse and had lower likelihood to violate the red light. However, this study reveals that older pedestrians have a higher likelihood to violate the red light. It could be because of the low educational attainment of older peoples in Hong Kong. Moreover, it is interesting to find that propensity of red light running of older pedestrians would reduce when there is a companion.

For the environmental features, previous studies indicate that when there is a pedestrian signal countdown device, 'time to green' is positively associated with the propensity of red light running. This study reveals that similar phenomenon can occur even when the pedestrian signal countdown device is absent in Hong Kong. More importantly, social norms, as reflected by the presence and behavior of other pedestrians, has a favorable effect on the propensity. Moreover, pedestrians who have a companion can be even more motivated (by the traffic violation of other pedestrians), compared with the pedestrians who are alone. Such finding is indicative to the effective enforcement and educational strategies that could enhance the safety awareness of targeted pedestrian group and deter against the red light running violation of pedestrians. Moreover, it is worth exploring the effectiveness of advanced traffic control techniques, i.e. variable pedestrian signal time that is responsive to pedestrian volume and pedestrian signal countdown device, in combating the red light running violation of pedestrians. In the extended research, effects of social norms, safety perception and anticipated traffic condition on the propensity of red light running violation can be gauged using an attitudinal model. Therefore, understanding on the pedestrian crossing behavior, and the interventions by the personal and environmental factors can be enhanced.

Nevertheless, this study has some limitations. First, we focus on the role of personal and environmental factors on the propensity of red light running of pedestrian. The safety outcome (i.e. associated crash risk) is out of the study scope. Second, effect of vehicular speed on the red light running behavior of pedestrians is not assessed. In the extended study, it is worth exploring the interactions between pedestrians and vehicles when comprehensive information on the traffic flow characteristics (i.e. flow, density and speed) and vehicle trajectories are available.

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TABLES AND FIGURES

Table 1. Descriptions of the sites investigated

No.	**Location**	**Number of traffic lane**	**Crosswalk width (meter)**	**Average traffic volume (/lane/hour)**	**Average pedestrian volume (/meter/hour)**
1	Prince Edward Road West j/w Nathan Road	4	5.5	275	410
2	Argyle Street j/w Nathan Road	4	6.5	310	362
3	Argyle Street j/w Sai Yee Street	2	4	219	217
4	Tonkin Street j/w Shun Ning Road	4	5.5	165	234
5	Hung Hom South Road j/w Po loi Street	2	4	105	154
6	To Kwa Wan Road j/w Chi Kiang Street	2	4	125	258

Table 2. Descriptive statistics of the sample

Category	Factor	Level	Attribute	Count	Mean	%	Std. dev.
Outcome	Red light running violation	Individual	No	5151		81.5%	
			Yes	1169		18.5%	
Demographics	Gender	Individual	Male	3103		49.1%	
			Female	3217		50.9%	
	Age	Individual	Adolescent	1630		25.8%	
			Adult	2965		46.9%	
			Elderly	1725		27.3%	
Other personal characteristics	With baggage	Individual	No	5493		86.9%	
			Yes	827		13.1%	
	With children	Individual	No	6155		97.4%	
			Yes	165		2.6%	
	With a companion	Individual	No	4746		75.1%	
			Yes	1574		24.9%	
Behavior of other pedestrians	Other pedestrians in the cycle violated red light	Individual	No	4431		70.1%	
			Yes	1889		29.9%	
	Number of people waiting upon arrival	Individual	Min = 0; Max = 40		7.7		7.4
Signal time	Time to green	Individual	Min = 0; Max = 130		35.48		24.4
	Waiting time	Individual	Min = 0; Max = 131		30.99		6.5
	Red time	Cycle	Min = 37; Max = 144		72.5		23.7
Traffic condition	Pedestrian arrival rate (per minute)	Cycle	Min = 1.5; Max = 41.6		18.4		8.4
	Traffic volume	Cycle	Min = 2.4; Max = 49.6		26.7		11.9
	Percentage of heavy vehicles	Cycle	Min = 0; Max = 90		28.6		12.8

Number of pedestrians = 6320; Number of cycles = 652

Table 3. Results of parameter estimation

Category	Factor		Model 1		Model 2	
			Coefficients	Z-value	Coefficients	Z-value
Constant			-1.390**	6.96	-1.511**	6.85
Demographics	Gender (Control: male)	Mean	-0.405**	-5.71	-0.433*	-3.59
		S.D.	*(0.372**)*	4.82	*(1.163**)*	8.62
	Adolescent (Control: adult)		-0.181*	-2.17	-0.228*	-2.31
	Elderly (Control: adult)		0.189*	2.18	0.174*	2.02
Other personal characteristics	With baggage		IS		IS	
	With children		IS		IS	
	With a companion		-0.546**	-5.41	-0.984*	-5.27
Behavior of other pedestrians	Others in the cycle violated red light		1.392**	18.29	1.029**	8.74
	Number of people waiting upon arrival	Mean	-0.379**	-9.68	-0.394**	-9.48
		S.D.	*(0.214*)*	3.88	*(0.253*)*	3.64
Signal time	Time to green		0.072**	4.41	0.090**	4.84
	Red time		0.061*	2.16	0.060**	2.12
Geometric design	Number of lanes		-0.803**	-7.13	-0.827**	-7.15
Traffic condition	Pedestrian arrival rate		IS		IS	
	Traffic volume		-0.025*	-3.12	-0.021*	-2.73
	Percentage of heavy vehicles		-0.016**	-4.76	-0.018**	-5.12
Interaction term	Gender x Traffic volume		-		-0.021**	-2.97
	Gender x Others violated red light		-		0.515**	3.30
	Elderly x With a companion				-0.221*	-2.03
	Elderly x Others violated red light				0.126^	1.89
	Others violated red light x With a companion		-		0.996**	4.47
Goodness-of-fit	AIC		2776.6		2750.1	
	Restricted loglikelihood		-1373.52		-1357.43	
	Unrestricted loglikelihood		-1365.42		-1350.12	
	Chi-square statistics		24.20		14.31	

Notes:

*** denotes statistically significance at the 1% level*

** denotes statistically significance at the 5% level*

^ denotes marginally significance at the 10% level

IS denotes insignificant

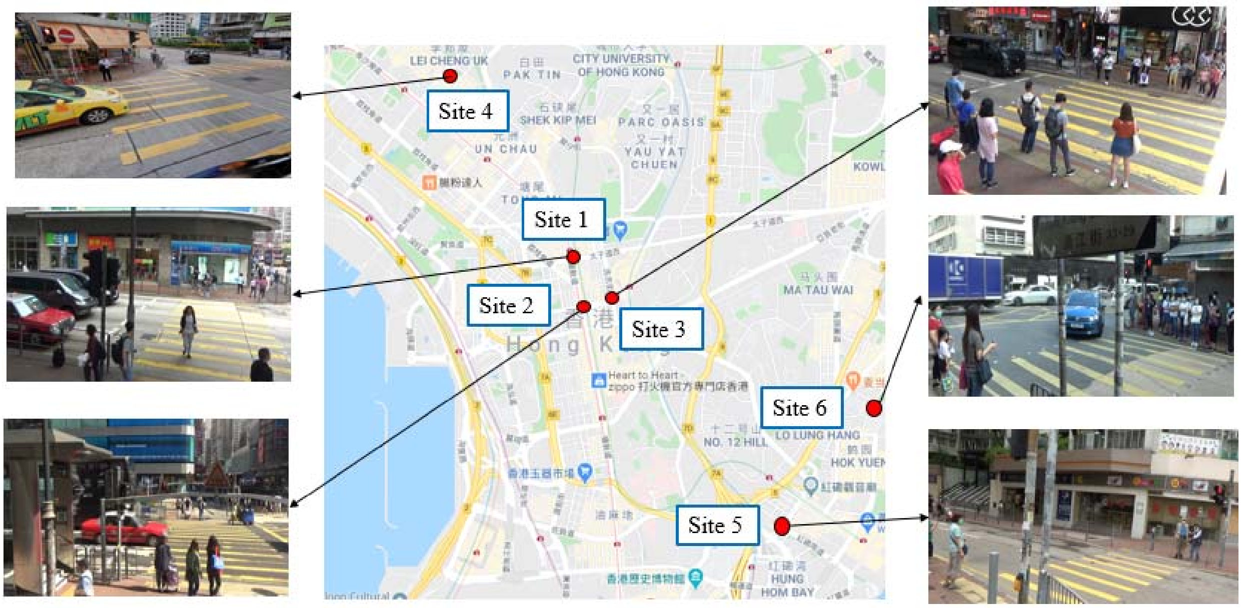
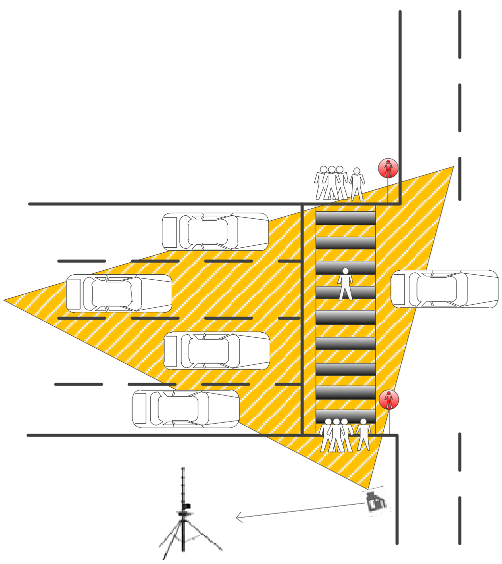
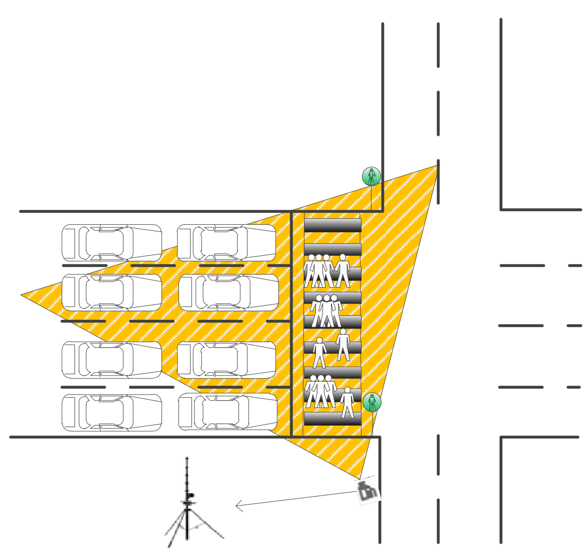


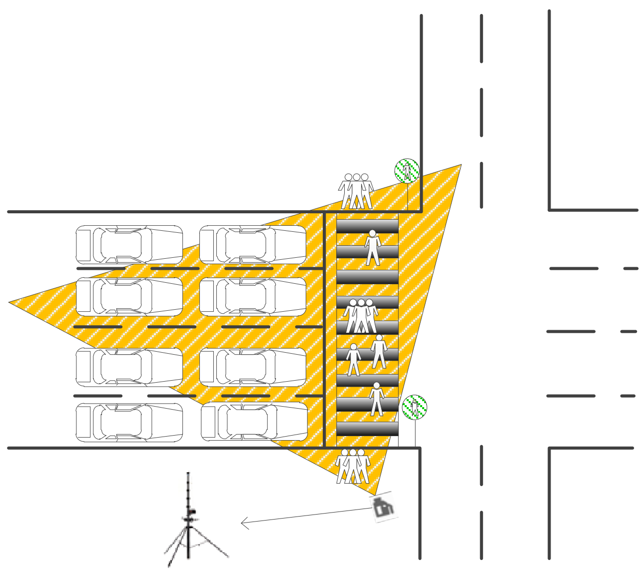
Figure 1 Illustration and location of the sites investigated



(a) Red



(b) Green



(c) Flashing green

Figure 2 Illustration of the three pedestrian signal phases

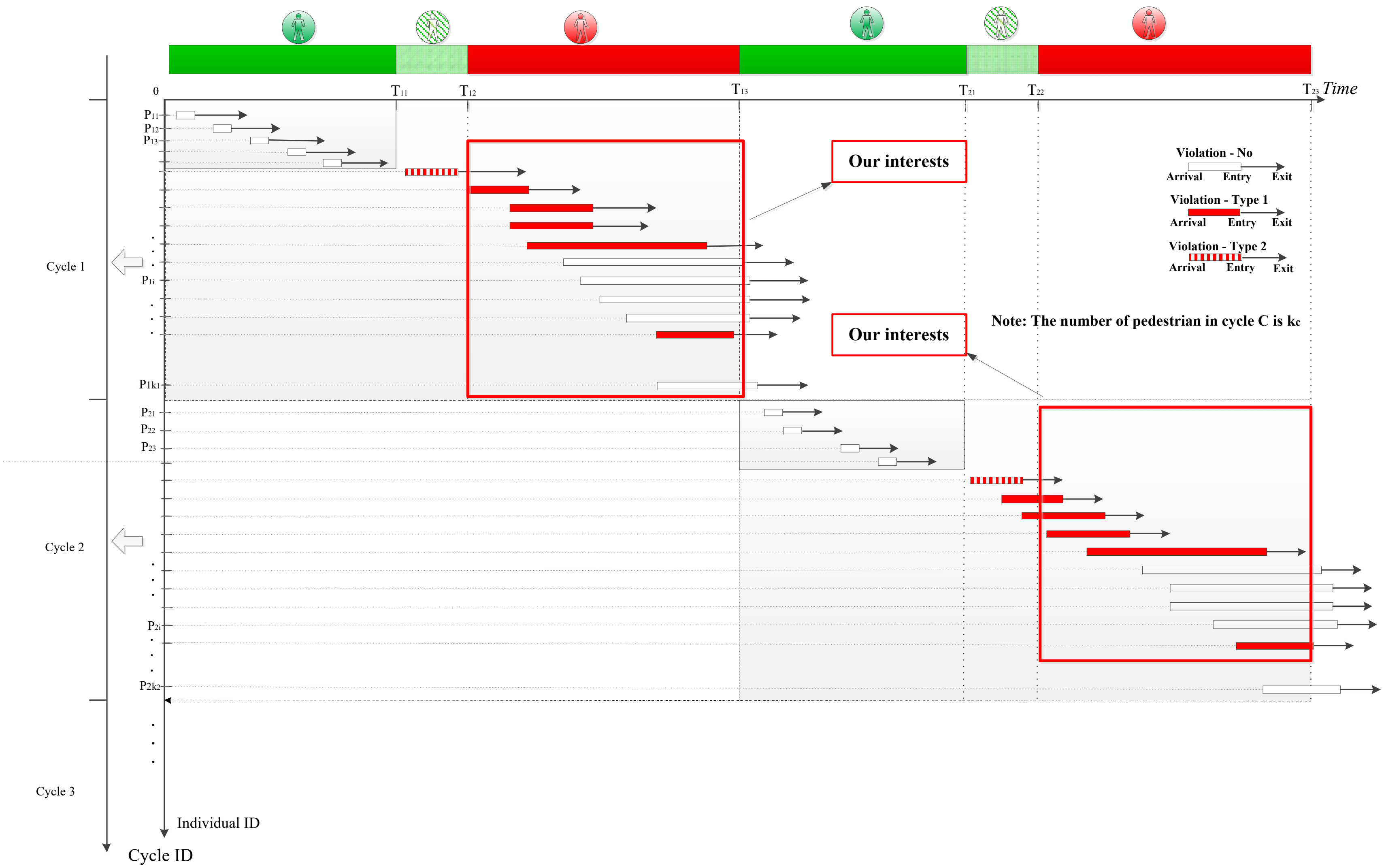


Figure 3 Illustration of method of data collection and coding