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The trade-off between safety and time in the red light running behaviors of pedestrians: A random regret minimization approach

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ABSTRACT

Pedestrian safety has been a major concern in Hong Kong, where walking is an important access mean to urban transportation services and pedestrian-vehicle conflicts are prevalent. Red light running violation of pedestrians is a leading cause of pedestrian-vehicle crashes at the signal intersections. It is necessary to examine the possible factors including personal characteristics and road environments that affect the propensities of red light running violation of pedestrians. Therefore, effective traffic control and enforcement measures can be implemented to deter against the red light running behaviors of pedestrians. This study attempts to examine the roles of trade-off between safety and time, as well as situational features and personality traits, in the red light running behaviors of pedestrians using a stated preference survey method. Then, a regret-based panel mixed multinomial logit model is established for the association measure between propensities of red light running violation and possible factors, with which the effects of unobserved heterogeneity and correlation in the choices between different scenarios of the same person are considered. Results indicate that the choice decision of pedestrians are more sensitive to a reduction in time loss, as compared to the equivalent increase in safety risk. In addition, the safety versus time trade-off may vary between pedestrian groups. Furthermore, presence and type of another violator also significantly affect the propensities of red light running violation. Such findings are indicative to effective policy interventions that can deter against the red light running behaviors of vulnerable pedestrian groups. Therefore, overall pedestrian safety level can be improved in the long term.

Keywords: Red light running violation; pedestrian safety; risk perception; stated preference survey; regret minimization approach

1. INTRODUCTION

Pedestrian safety has been of major concern in road safety research as pedestrians are more vulnerable to fatality and severe injury in the road crashes, as compared to car occupants. Red light running violation of pedestrians is one of the key contributory factors that affect the risk of pedestrian-vehicle crashes (Wang et al., 2020a). It constitutes a quarter of pedestrian-involved crashes at the signal intersections (Zhu et al., 2021). In Hong Kong, pedestrians who are found committing red light running offences would be liable to a monetary fine of 2,000 HKD (equivalent to 258 USD) (Department of Justice, 2020). Unlike the enforcements against speeding and red light running offences of drivers (using automated enforcement system), enforcement against red light running offence of pedestrians relies heavily on manual enforcement. This could reduce the perceived probability of being caught and punished of pedestrians for any violation offence. Hence, the deterrent effect of any penalty against red light running violation of pedestrians could be diminished (Chen et al., 2020a; Zhu et al., 2020). It would be crucial to improve the understanding on the personal characteristics (e.g., demographics, socioeconomics, and personality) and situational features (e.g., traffic conditions, weather conditions, and traffic control) that may affect the intentions of red light running of pedestrians (Zhu et al., 2021; Zhu and Sze, 2021). Therefore, effective traffic control measures and enforcement strategies can be implemented to deter against the red light running offence of pedestrians.

Numerous studies have contributed to the literature by measuring the relationship between the red light running behaviors of pedestrians and possible explanatory factors including personal characteristics, road environments (e.g., geometric design, pavement surface condition, and weather conditions), social influences (e.g., number and behaviors of other pedestrians around), traffic conditions (e.g., traffic volume, traffic composition, and vehicular speed), and signal time phase based on observational surveys (Kim et al., 2008; Rosenbloom, 2009; Brosseau et al., 2013; Russo et al.,2018; Wang et al., 2019b; Mukherjee and Mitra, 2020; Zhu et al., 2021). Alternately,

it is possible to examine the effects of safety awareness and attitude, social norms, and conformity tendency on the intentions of red light running violation of pedestrians using attitudinal surveys based on different psychological frameworks, i.e., theory of planned behavior (TPB) (Evans and Norman, 1998; Yagil, 2000; Zhou et al., 2010; Zhou et al., 2016). However, to the best of our knowledge, it is rare that the intentions of red light running behavior are evaluated based on the situational decision of individuals with respect to the trade-off between safety risk (i.e., road injuries) and time. In addition, moderation effects by the situational features and personal characteristics on individual's decision should be considered.

Stated preference (SP) approach is an efficient survey method to gauge the choice decision of individual in different scenarios with which the attribute levels of more than one factors are varying, in the analyses of transport mode choice (Loo et al., 2006; Ho et al., 2020), travel behavior (Anciaes and Jones, 2020; Zhao et al., 2021), and traffic safety (Steinbakk et al., 2019; Li et al., 2020). SP method has been applied to investigate the perception and attitudes towards the enforcement strategies and penalties against traffic offences including red light running and speeding violations of occupational drivers (Wong et al., 2008; Chen et al., 2020a). In addition, trade-off between different penalties including monetary fine, driver demerit points, and driving disqualifications deterring against different extents of drink driving offense, in terms of frequency of conviction and alcohol concentration, were investigated (Li et al., 2014). Compared to observational survey and revealed preference (RP) survey, SP method is capable of evaluating the effectiveness of policy strategies that have not yet been implemented (while being realistic and consistent to the actual environment) (Loo et al., 2006). This should shed light on the effective enforcement strategies that can deter against different traffic offences.

However, there could be considerable variations in the intentions among individuals who share the same demographic and socioeconomic characteristics under identical situation (Chen et al., 2020a). Intentions of traffic violation behavior are sensitive to risk perception, subjective norms, and

perceived behavioral control of individuals, in accordance with TPB (Wang et al., 2019a; Zhou et al., 2016). Risk perception refers to the rational or irrational beliefs of a person regarding the likelihood of any negative consequence associated with a hazard event. For the red light running violations, negative consequences are injuries and material loss resulting from potential pedestrian-vehicle conflicts and collisions (Chambers, 2004). Subjective norms are the normative expectations of what a person believes that other peoples, including his or her family members, friends, peers and other members in the society, think he or she ought to do (i.e., comply with the traffic signal or not). Perceived behavioral control indicates the perceived capability (i.e., confidence) of a person to execute an act (i.e., violate the traffic signal and cross the road) (Ajzen, 1991; Evans and Norman, 1998). It is necessary to account for the moderation effects of personality trait and safety attitudes on the association between demographic and socioeconomic characteristics, situational features, and propensities of red light running violation of pedestrians (Rosenbloom, 2009; Zhu et al., 2021). In addition, interference by the presence of another pedestrian who violates the signal (and whether that pedestrian is an adolescent, normal adult or elderly) on the intentions of red light running violation should be investigated (Rosenbloom, 2009; Zhu et al., 2020). This would be useful for the development and implementation of targeted road safety education for vulnerable pedestrian groups.

Red light running behaviors of pedestrians can be stratified into two: (1) cross immediately once arriving at the crosswalk; and (2) wait until there is a suitable gap and cross. They are usually modeled separately in preceding studies. For instance, discrete outcome methods, e.g., logit and probit models, are applied to model the likelihood of whether a pedestrian would violate the red light or not (Wang et al., 2019; Zhu and Sze, 2021). On the other hand, survival methods are applied to model the (waiting) time-to-violate of pedestrians based on the gap acceptance theory (Hamed, 2001; Koh and Wong, 2014; Zhang and Fricker, 2020). From the methodological perspective, it is capable to model the choice among three alternatives: (i) comply with pedestrian signal; (ii) not comply but wait for a suitable gap; and (iii) not comply and cross immediately, in a single

framework. It is expected that risk-taking pedestrians tend to cross immediately for the higher anticipated benefit (i.e., time saving), and risk-averse pedestrians are willing to sacrifice some benefit and comply with the signal (or wait for a suitable gap). Results of the willingness of pedestrians to trade-off between anticipated time saving and perceived risk of road injuries should be indicative to efficient signal time plan and initiatives including flashing warning signs and pedestrian signal countdown devices that could improve the pedestrian safety at the signal intersections (Zhu et al., 2020).

1.1. The current paper

In this study, we attempt to examine the roles of personal characteristics, social influences and road environments in the intentions of red light running behavior of pedestrians based on the situational decision for the trade-off between safety and time, using the SP method (Zhou et al., 2009; Elvik, 2019; Zhu et al., 2021). In addition, effects of three situational features including weather condition, presence (and type) of other pedestrian who violates, and presence of a warning sign on the trade-off are also considered (Mukherjee and Mitra, 2020; Zhu and Sze, 2021). Furthermore, information on personal characteristics including demographic and socioeconomic characteristics (i.e., gender, age, educational level, and income), travel habit (i.e., frequency of walking travel, number of trips making days per week, and possession of driving license), and personality traits (i.e., safety perception, subjective norms, perceived behavioral control, and legal awareness) are collected in the survey. To model the (discrete) choice decision, prevalent estimation method is the random utility maximization (RUM) approach. RUM-based approach assumes that a decision maker prefers choice that can provide the highest level of satisfaction (Train, 2009). However, RUM-based approach may also allow for self-compensation between underperforming and outperforming attributes (Chorus et al., 2008). In behavioral science, alternative modeling approaches based on the decision rules including relative advantage maximization (Leong and Hensher, 2015), contextual concavity (Kivetz et al., 2004), fully-compensatory decision making (Arentze and Timmermans, 2007), and random regret

minimization (RRM) (Chorus et al., 2008, Chorus, 2010) have been proposed. Among them, RRM is a promising alternative for its mathematical simplicity (Iraganaboina et al., 2021). In this study, a regret-based multinomial logit model is adopted to estimate the effects of possible explanatory factors on the propensities of red light running violation of pedestrians. It is expected that the personality traits would moderate the association between anticipated waiting time, perceived safety risk, situational features, and intentions of red light running violation. Nonetheless, effect of unobserved heterogeneity on the association would be considered using a mixed logit approach (Mannering et al., 2016).

The remainder of this paper is structured as follows. Section 2 describes the methods of data collection and analysis. Section 3 summarizes the data used in the analysis. Section 4 and Section 5 present the results of mixed multinomial logit regression model and interpretations. Section 6 concludes the study with a summary of findings, policy implications, and future research directions.

2. METHOD

2.1 Questionnaire survey

Intentions of red light running violation of pedestrians were investigated using an online survey in the period from September to November in 2020. The questionnaires were distributed through social media posts and QR code on the smartphones or tablets (at the locations including the entrances of schools, shopping malls and public transport stations) with the help of several part-time research assistants. It is to avoid the questionnaires from reaching a restricted range of participants only and increase the sample diversity with respect to demographics and socio-economics. To increase the response rate, a snowball sampling method was also applied.

The questionnaire has four parts: (1) SP experiments on the intentions of red light running violation; (2) personality traits; (3) travel habit (e.g., trip frequency, and frequency of walking travel); and

(4) demographics and socio-economics (e.g., gender, age, educational level, and income). In the second part, attributes including subjective norms, perceived behavioral control, risk perception and legal awareness will be gauged using the five-point Likert scale (Jiang et al., 2017a). For instance, four questions, e.g. "Do you think your family members will agree with the act of violating the pedestrian signal?", "Do you have any difficulty when making the choice decision of crossing the roads?", "Do you think you are risk-taking?", and "Do you think obeying the traffic rules is important?" are adopted.

2.2 SP design

Table 1 illustrates the choice alternatives and factor attributes considered in the SP design. As shown in Table 1, trade-offs between anticipated waiting time and perceived relative safety risk for three choice alternatives: (i) comply with the pedestrian signal; (ii) not comply but wait for a suitable gap to cross; and (iii) not comply and cross immediately, are measured. There are two attribute levels for both anticipated waiting time (i.e., 30, 20, and 0 second versus 50, 35, and 0 second) and perceived relative safety risk (i.e., 0%, 20%, and 50% versus 0%, 30%, and 60%). Since the common cycle length in Hong Kong is 120 seconds, the waiting times adopted in the SP design are commonly experienced. For situational features, there are two levels for the weather condition (i.e., fine weather versus raining condition), four levels for the presence and type of other pedestrian who violates the red light (i.e., no, adolescent, normal adult, and elderly), and two levels for the presence of warning sign (i.e., yes and no). To provide realistic choice scenarios, illustrations were developed based on an actual pedestrian crossing in the urban area of Hong Kong. In addition, variations in the attributes including weather condition, presence and type of other pedestrian who violates, and presence of warning sign can be revealed in the illustrations (For details, readers may refer to a typical illustration shown in **Figure A1** of the **Appendix**).

Since there are five factors (with the number of attribute levels ranging from two to four) in the SP design, there would be (4 x 2 x 2 x 2 x 2 =) 64 combinations of factor attributes if the full factorial

design were adopted. It is however not efficient and practical to gauge the respondents' decision when all the 64 choice scenarios are considered. Hence, an orthogonal fractional factorial design is adopted, and the number of scenarios is reduced to eight (Bhat and Sardesai, 2006; Hössinger and Berger, 2012; Li et al., 2014; Chen et al., 2020a). In addition, the eight choice scenarios are stratified into two sub-sets using a randomized block design approach. Therefore, there are only four scenarios presented to each respondent to avoid overwhelming information.

Table 1. Factors and attributes considered in the SP design

Factor		Attribute		
		Choice 1: Comply with pedestrian signal	**Choice 2: Not comply but wait for a suitable gap**	**Choice 3: Not comply and cross immediately**
Anticipated waiting time	Level 1	30 second	20 second	0 second
	Level 2	50 second	35 second	0 second
Perceived relative risk	Level 1	0%	20%	50%
	Level 2	0%	30%	60%
Weather condition	Level 1	Fine weather		
	Level 2	Raining condition		
Presence and type of violator	Level 1	No violator		
	Level 2	Adolescent		
	Level 3	Normal adult		
	Level 4	Elderly		
Presence of warning sign	Level 1	No		
	Level 2	Yes		

2.2. Modelling framework

In conventional studies, multinomial logit model has been applied to model the discrete outcome, e.g., choice between more than two unordered alternatives. To account for the effect of unobserved heterogeneity among different individuals, a mixed logit approach is adopted. In addition, to resolve the problem of correlation in the choices between different observations of the same individual in the panel data, a simulation approach using the Halton draw method is applied to estimate the parameters of proposed model (Train, 2001, 2009; Chen et al., 2020a).

In the formulation of proposed regret-based model, i (i = 1, 2, …, I) is the indicator variable of individual, j (j = 1, 2, …, J, and J = 4) is the indicator variable of choice scenario, k (k = 1, 2, …, K, and K = 3) is the indicator variable of choice alternative, s denotes other viable alternative, and m (m = 1, 2, …, M) is the indicator variable of factor attribute. Then, the random regret RR_{ijk} of alternative k in scenario j of individual i can be given by,

$$RR_{ijk} = \sum_{s \neq k} \sum_{\forall m} ln\{1 + \exp[(\alpha' + \rho_i')(z_{ismj} - z_{ikmj})]\}\varepsilon_{ijk} \quad (1)$$

where z_{ikmj} denotes the vector of factor attributes of chosen alternative k and z_{ismj} denotes that of other alternative s, α' is the vector of coefficients that reflects the mean effects, ρ_i' is the vector of coefficients that reflects the effect of unobserved heterogeneity of individual i (assumed to be normally distributed), and ε_{ijk} is the error term (assumed to be identically and independently Gumbel distributed).

Then, the probability of choosing alternative k can be written (McFadden, 1978) as,

$$P_{ijk} = \frac{e^{-RR_{ijk}}}{\sum_{k=1}^{K} e^{-RR_{ijk}}} \quad (2)$$

The unconditional probability can then be computed as,

$$P_{ik} = \int_{\rho_i'} (P_{ijk} \mid \rho_i') dF(\rho_i' \mid \sigma) \quad (3)$$

where $\boldsymbol{F}$ is the multivariate cumulative normal distribution.

Conditional on ρ_i, the likelihood function of observed sequence of choices of individual i is given by,

$$L_i(\alpha \mid \rho_i) = \prod_{j=1}^{J} [\prod_{k=1}^{K} \{P_{ijk} \mid \rho_i\}^{\delta_{ijk}}] \quad (4)$$

where δ_{ijk} is an indicator variable that takes the value of 1 when individual i chooses alternative k in scenario j, and 0 otherwise.

Eventually, the unconditional likelihood function is given by,

$$L_i(\alpha,\sigma) = \int_{\rho_i} L_i(\alpha \mid \rho_i) dF(\rho_i \mid \sigma) \quad (5)$$

where the log-likelihood function is $L(\alpha,\sigma) = \sum_i lnL_i(\alpha \mid \sigma)$.

A simulation approach is applied to estimate the integrals of the likelihood function and maximize the simulated likelihood function across all individuals with respect to the parameters. Under the weak regularity conditions, the maximum (log) simulated likelihood (MSL) estimator is consistent, asymptotically efficient, and asymptotically normal (see Hajivassiliou and Ruud, 1994; Lee and Carter, 1992; McFadden and Train, 2000). Furthermore, Halton sequences are used to draw the realizations for ρ_i from the prevailing normal distributions. For the details of Halton sequence, readers may refer to Bhat (2001, 2003) and McFadden and Train (2000). With the Halton sequence, the draws from a single observation can fill all the empty spaces. Therefore, the simulated probabilities would be negatively correlated. Such negative correlation can reduce the variance of the log-likelihood function. It should be noted that the negative correlation still exists in the simulated probabilities between observations, even when some attributes of different observations are identical for the panel data (Train, 2001).

3. Data

A total of 1,007 respondents completed the questionnaire survey. As four choice scenarios were presented to each respondent, there were 1,007 × 4 = 4,028 observations in the dataset. **Table 2** illustrates the distribution of choice decisions. Of the 4,028 observations, 2,105 (52.3%) comply with pedestrian signal, 1,399 (34.7%) not comply but wait for a suitable gap, and 524 (13.0%) not comply and cross immediately respectively. Distributions of choice decision in different scenarios are shown in **Table 2**. As shown in Table 2, proportion of "comply with pedestrian signal" tends to increase when relative risk level is higher, anticipated waiting time is shorter, it is under raining condition, there is no other violator, and there is a warning sign. In this study, effects of the trade-

off between perceived relative risk and anticipated waiting time, as well as the interactions by situational features and personal characteristics, on the intentions of red light running violation of pedestrians would be gauged.

Table 2. Distributions of choice decision in different scenarios

Scenario	SP attribute					Choice decision		
	Waiting time	**Perceived relative risk**	**Weather condition**	**Presence and type of violator**	**Presence of warning sign**	**Choice 1: Comply with pedestrian signal**	**Choice 2: Not comply but wait for a suitable gap**	**Choice 3: Not comply and cross immediately**
1	(30 sec, 20 sec, 0 sec)	(0, 20%, 50%)	Fine weather	No	No	185 (39.7%)	197 (42.3%)	84 (18.0%)
2	(50 sec, 35 sec, 0 sec)	(0, 30%, 60%)	Fine weather	Adolescent	No	157 (33.7%)	203 (43.5%)	106 (22.8%)
3	(50 sec, 35 sec, 0 sec)	(0, 20%, 50%)	Raining condition	Normal adult	No	284 (60.9%)	139 (29.8%)	43 (9.0%)
4	(50 sec, 35 sec, 0 sec)	(0, 20%, 50%)	Fine weather	Elderly	Yes	285 (61.2%)	131 (28.1%)	50 (10.7%)
5	(30 sec, 20 sec, 0 sec)	(0, 30%, 60%)	Raining condition	Elderly	No	272 (50.3%)	218 (40.3%)	51 (9.4%)
6	(50 sec, 35 sec, 0 sec)	(0, 30%, 60%)	Raining condition	No	Yes	353 (65.2%)	134 (24.8%)	54 (10.0%)
7	(30 sec, 20 sec, 0 sec)	(0, 20%, 50%)	Raining condition	Adolescent	Yes	322 (59.5%)	172 (31.8%)	47 (8.7%)
8	(30 sec, 20 sec, 0 sec)	(0, 30%, 60%)	Fine weather	Normal adult	Yes	247 (45.7%)	205 (37.9%)	89 (16.4%)

3.1 Demographics, socio-economics and travel habit

Table 3 summarizes the demographics and socio-economics of the respondents. Overall, ratio of male to female is 780 to 1,000. It is consistent to that of Hong Kong population (male to female equal to 830 to 1,000) (Census and Statistic Department, 2018a). For the age distribution, proportion of the respondents between the age of 18 and 24 is relatively high, and that of over 55 years is 10.2% only. For the educational level, 86.5% of respondents have attained secondary education or above. For the marital status, 39.2% of respondents are married (50.1% for Hong Kong population) (Census and Statistic Department, 2018b). Furthermore, monthly incomes of 37.9% of respondents are less than HK$10,000, and that of 18.2% of respondents are more than HK$30,000 respectively (where the median monthly income in Hong Kong was about HK$15,000 (Census and Statistic Department, 2018b). For the travel habit, 36.4% of respondents have a driving license. In addition, half of the respondents (50.1%) travel almost every day, and 39.2% of respondents walk more than six times a day. This could be attributed to the promotion of walkability and improvement in walking environments in Hong Kong (Chen et al., 2020b). Despite that the sample may be skewed, there should not be any adverse impact on the interpretation since all segments in terms of gender, age, income, and education level are adequately represented. Additionally, there is no significant discrepancy between the stated choices in this study and revealed behaviors in preceding observational survey (Zhu and Sze, 2021).

3.2. Attitude and personality traits

Four variables that characterize the personality of respondents are measured. For the subjective norms, 37.4% of respondents consider that their family members would not agree with the violation behaviors, while 34.3% would agree. For the perceived behavioral control, majority of respondents (68.0%) consider themselves as having low behavioral control. For the risk perception, 35.7% of respondents are risk-taking, and 33.1% are risk-averse respectively. For the legal awareness, majority of respondents (59.3%) consider themselves as having high awareness. Despite that these four variables are commonly adopted in other TPB-based studies, whether the

attitude and personality traits of respondents can represent that of Hong Kong population should be assessed when comprehensive empirical data were available.

Table 3. Distribution of the sample

Category	Factor	Attribute	Count	%
Demographics	Gender	Male	444	44.1
		Female	563	55.9
	Age	18 to 24 years old	428	42.5
		25 to 54 years old	470	46.7
		55 years old or above	109	10.8
Socio-economics	Educational level	Primary or below	135	13.5
		Secondary	217	21.5
		Tertiary or above	655	65.0
	Marital status	Unmarried	612	60.8
		Married with no children	157	15.5
		Married with children	238	23.7
	Monthly income	Less than 10,000 HKD	382	37.9
		10,000 – 19,000 HKD	251	24.9
		20,000 – 29,000 HKD	191	19.0
		30,000 HKD or above	183	18.2
Travel habit	Possession of driving license	No	638	63.4
		Yes	369	36.4
	Walking trip frequency per day	None	30	3
		1 – 2 times	206	20.5
		3 – 5 times	376	37.3
		6 times or more	395	39.2
	Number of trip making day per week	0 day	9	0.9
		1 – 2 days	91	9.0
		3 – 5 days	403	40.0
		6 – 7 days	505	50.1
Attitude and personality traits	Family norms towards the violation behavior	Agree	343	34.1
		Neutral	287	28.5
		Disagree	377	37.4
	Perceived behavioral control	High	117	11.6
		Medium	205	20.4
		Low	685	68.0
	Risk perception	Risk-taking	360	35.7
		Risk-neutral	314	31.2
		Risk-averse	333	33.1
	Legal awareness	High	597	59.3
		Medium	256	25.4
		Low	154	15.3

4. RESULTS

In this study, a regret-based panel mixed multinomial logit model is adopted to measure the association between possible explanatory factors and intentions of red light running violation of pedestrians. For the random components of coefficients, typical distributions including normal, Gumbel and log-normal are considered. Specifically, mixed model based on normal distribution provides the best fit. **Table 4** summarizes the results of parameter estimation for: (i) Choice 2: not comply but wait for a suitable gap; and (ii) Choice 3: not comply and cross immediately.

4.1 Trade-off between waiting time and relative safety risk

Variables including anticipated waiting time and perceived relative risk are alternative-specific. Hence, their parameter estimates are the same for Choice 2 - "not comply but wait for a suitable gap" and Choice 3 – "not comply and cross immediately". As shown in **Table 4**, anticipated waiting time is positively associated with the propensity of red light running violation (β = 0.02), at the 1% level of significance. This indicates that pedestrians tend to have less regret for running the red light when anticipated waiting time increases. In contrast, perceived relative risk is negatively associated with the propensity of red light running violation (β = -1.42), at the 1% level of significance. This implies that pedestrians tend to have greater regret for running the red light when the perceived safety risk increases.

4.2 Situational features

As shown in **Table 4**, propensities of red light running violation in the raining condition are significantly lower (Choice 2, -0.86; Choice 3, -1.26) than that in the fine weather condition, at the 1% level. In addition, propensities of red light running violation (Choice 2, -0.32; Choice 3, -0.26) are significantly lower when there is a warning sign, at the 1% level. Furthermore, propensities of red light running violation are significantly higher (Choice 2, 0.23; Choice 3, 0.21) when an

adolescent violator is present, at the 5% level. However, propensity of "not comply and cross immediately" (Choice 3) is significantly lower (-0.25) when an elderly violator is present, at the 5% level.

4.3 Demographics, socio-economics, and travel habit

For the effects of personal characteristics including demographics, socio-economics and travel characteristics, as also shown in **Table 4**, propensities of red light running violation of males are significantly higher (Choice 2: 0.53; Choice 3: 0.36) than that of females, at the 1% level. In addition, propensities of red light running violation of respondents who are 18 to 24 years old are significantly higher (Choice 2: 0.42; Choice 3: 1.29) than that who are 25 to 55 years old, at the 5% level. Also, propensities of red light running violation of respondents who have attained tertiary education or above are significantly lower (Choice 2: -0.12; Choice 3: -0.29), at the 5% level. Furthermore, propensities of red light running violation of respondents who have higher salaries (i.e., 20,000 HKD per month or above, Choice 2: 0.17; Choice 3: 0.58) are significantly higher, at the 5% level. Nevertheless, propensities of red light running violation of respondents who have a driving license are significantly lower (Choice 2: -0.16; Choice 3: -0.15), at the 5% level. However, propensities of "not comply and cross immediately" (Choice 3) of respondents who walk three to five times a day (0.18), and travel on three to five days a week (0.31) are marginally higher, as compared to those who walk less than three times a day and travel less than three days a week, at the 10% level.

4.4 Attitude and personality traits

For the effect of pedestrians' perception, propensities of red light running violation of respondents whom their family members tend to agree with (Choice 2: 0.25; Choice3: 0.22) or neutral to (Choice 2: 0.32) the violation behaviors are higher, at the 1% level of significance. In addition, propensities of red light running violation of respondents who have medium (Choice 2: 0.46; Choice 3: 1.14) and high perceived behavioral control (Choice 2: 0.20; Choice 3: 0.81), and are

risk-neutral (Choice 2: 0.52; Choice 3: 0.64) and risk-taking (Choice 2: 0.46; Choice 3: 0.76) are significantly higher, at the 1% level. However, propensities of red light running violation of respondents who have medium (Choice 2: -0.32; Choice 3: -0.51) and high legal awareness (Choice 2: -1.05; Choice 3: -1.35) are significantly lower, at the 1% level.

4.5 Interaction effects

Interaction effects between personal attributes and perception on the propensities of red light running violations are also investigated. For example, "18 to 24 years old x family members agree with violation behavior" (Choice 2: 0.17) are positively associated with the propensities of red light running violation, at the 10% level. Also, "high perceived behavioral control x risk-taking" (Choice 2: 0.37; Choice 3: 0.10) are positively associated with the propensities of red light running violation, at the 5% level of significance. However, "18 to 24 years old x perceived relative risk" and "tertiary education or above x presence of warning sign" are negatively associated with the propensity of "not comply and cross immediately" (Choice 3), at the 5% level of significance.

Table 4. Results of parameter estimation of regret-based panel mixed multinomial logit model

Category	Factor	Attribute		Choice 2: Not comply but wait		Choice 3: Not comply and cross immediately	
				Coefficient	S.E.	Coefficient	S.E.
	Constant			IS		-1.36**	0.33
SP attribute	Waiting time		Mean	0.02**	0.01	0.02**	0.01
			SD	0.03**	0.01	0.03**	0.01
	Perceived relative risk			-1.42**	0.51	-1.42**	0.51
	Weather condition (Control: Fine)	Raining	Mean	-0.86**	0.14	-1.26**	0.31
			SD	0.57*	0.30	0.69**	0.24
	Presence of warning sign (Control: No)	Yes		-0.32**	0.11	-0.26**	0.07
	Presence of violator (Control: No)	Adolescent		0.23**	0.03	0.21*	0.10
		Normal adult		IS		IS	
		Elderly		IS		-0.25*	0.12
Demographics	Gender (Control: Female)	Male	Mean	0.53**	0.21	0.36**	0.15
			SD	0.45**	0.19	0.23**	0.09
	Age (Control: 24-55 years old)	18-24 years old		0.42*	0.22	1.29*	0.61
		55 years old or above		IS		IS	
	Educational level (Control: Secondary or below)	Tertiary or above		-0.12*	0.06	-0.29*	0.14
	Monthly income (Control: Less than 10000 HKD)	10000-19999 HKD		IS		0.31**	0.10
		20000 HKD or above		0.17*	0.09	0.58**	0.12
Travel habit	Holding a driving license (Control: No)	Yes		-0.16**	0.05	-0.15*	0.07
		3-5 times		IS		0.18*	0.08

	Walking trip frequency per day (Control: Twice or less)	6 times or more	0.12*	0.05	IS	
	Number of trips making day per week (Control: 2 days or less)	3-5 days	IS		0.31^	0.16
		6-7 days	IS		IS	
Attitude and personality trait	Family norms towards violation behavior (Control: Disagree)	Neutral	0.32**	0.12	IS	
		Agree	0.25**	0.11	0.22**	0.07
	Perceived behavioral control (Control: Low)	Medium	0.46**	0.08	1.14**	0.31
		High	0.20*	0.09	0.81**	0.30
	Risk perception (Control: Risk-averse)	Risk-neutral	0.52**	0.14	0.64**	0.24
		Risk-taking	0.46**	0.12	0.76**	0.18
	Legal awareness (Control: Low)	Medium	-0.32**	0.10	-0.51**	0.19
		High	-1.05**	0.06	-1.35**	0.11
Interaction term	18-24 years old x perceived relative risk		IS		-2.28*	0.98
	18-24 years old x family members agree with violation behavior		0.17^	0.10	IS	
	High perceived behavioral control x risk-taking		0.37**	0.13	0.10*	0.04
	Tertiary education or above x presence of warning sign		IS		-0.27*	0.13
Number of parameters			62			
Restricted log likelihood			-4226.50			
Unrestricted log likelihood			-3247.72			
McFadden Pseudo R-square			0.27			
AIC			6,612			

*Notes: ** Statistically significant at the 1% level; * Statistically significant at the 5% level; ^ Marginal at the 10% level; IS denotes Insignificant*

5. DISCUSSION

Table 5 summarizes and compares the results between current and previous studies. As shown in Table 5, findings of current study are generally consistent with that of the literature, particularly the effects of anticipated waiting time, weather condition, presence of the first violator, education level, monthly income, social influences, perceived behavior control, and risk-taking attitude on the propensities of red light running of pedestrians. However, it is rare that the effects of perceived risk, presence of warning sign, travel habit and legal awareness are investigated. Implications of current findings and recommendations of remedial measures that can deter against the red light running behavior of pedestrians are given in subsequent **Section 5.1-5.4**.

Table 5. Comparison between current and previous studies

Factor attribute	Current study	Previous studies	
Anticipated waiting time	↑	↑	van Houten et al., 2007; Brosseau et al., 2013; Zhu et al., 2021
Perceived safety risk	↓	Rarely attempted	
Raining condition	↓	↓	Li & Fernie, 2010; Liu & Tung, 2014
Presence of violator	↑	↑	Rosenbloom, 2009; Zhu et al., 2021
Presence of warning sign	↓	Rarely attempted	
Male	↑	↑	Guo et al., 2011
		↓	Ren et al., 2011
Young adult	↑	↓	Zhu et al., 2021
Educational level	↓	↓	Wu et al., 2014; Zhang et al., 2016
Monthly income	↑	↑	Zhang et al., 2016
Holding a driving license	↓	Rarely attempted	
Walking trip frequency per day	↑	Rarely attempted	
Family norms towards violation behavior	↑	↑	Zhou et al., 2016
Perceived behavioral control	↑	↑	Zhou et al., 2016
Risk-taking attitude	↑	↑	Zhou and Horrey, 2009
Legal awareness	↓	Rarely attempted	

Notes: ↑ Positively associated with the propensities of red light running violation of pedestrians

↓ Negatively associated with the propensities of red light running violation of pedestrians

5.1 Trade-off between waiting time and perceived risk

The positive association between anticipated waiting time and propensities of red light running violation, and negative association between perceived risk and propensities are expected. Also, effects of anticipated waiting time on the propensities are normally distributed (with standard deviation of 0.03). This implies that 75% of respondents would have higher tendency to violate the red light when waiting time increases. **Table 6** presents the results of sensitivity analysis of anticipated waiting time and perceived risk on the propensities. As shown in **Table 6**, 10% increase in anticipated waiting time is associated with 8.7% reduction in the likelihood of "comply with pedestrian signal". In contrast, 10% increase in perceived risk is associated with 1.1% increase in the likelihood of "comply with pedestrian signal". Apparently, compliance of pedestrian signal is less sensitive to the increase in perceived risk. This is because peoples tend to be loss-averse, as suggested by the prospect theory (Levy, 1992; Wakker, 2010; Andersson et al., 2019). For example, peoples usually hate losses more than the same extent of gains. To this end, travelers are more willing to take risk to avoid a loss, i.e., time delay (Jou and Chen, 2013; Wang and Zhao, 2019; Flügel et al., 2019; Hu et al., 2019).

To this end, risk-return rate can be estimated to indicate the trade-off between safety (risk) and time (return) using the formulation given by (Iraganaboina, 2021),

$$RR = \frac{\sum_{s \neq k} -\beta_t \left(1 + \frac{1}{exp[\beta_t (t_k - t_s)]}\right)}{\sum_{s \neq k} -\beta_r \left(1 + \frac{1}{exp[\beta_r (r_k - r_s)]}\right)} \quad (6)$$

where β_t and β_r are parameter estimates of anticipated waiting time and perceived safety risk respectively, t_k and t_s are waiting times for alternative k and s respectively, and r_k and r_s are perceived safety risks for alternative k and s respectively.

Figure 1 illustrates the changes in the risk-return rate with respect to perceived safety risk and waiting time. As shown in **Figure 1**, risk-return rate ranges from 0.5 to 1.5 (% per second). In

other word, pedestrians are willing to accept 15 to 44% increase in safety risk for the saving of 30 seconds.

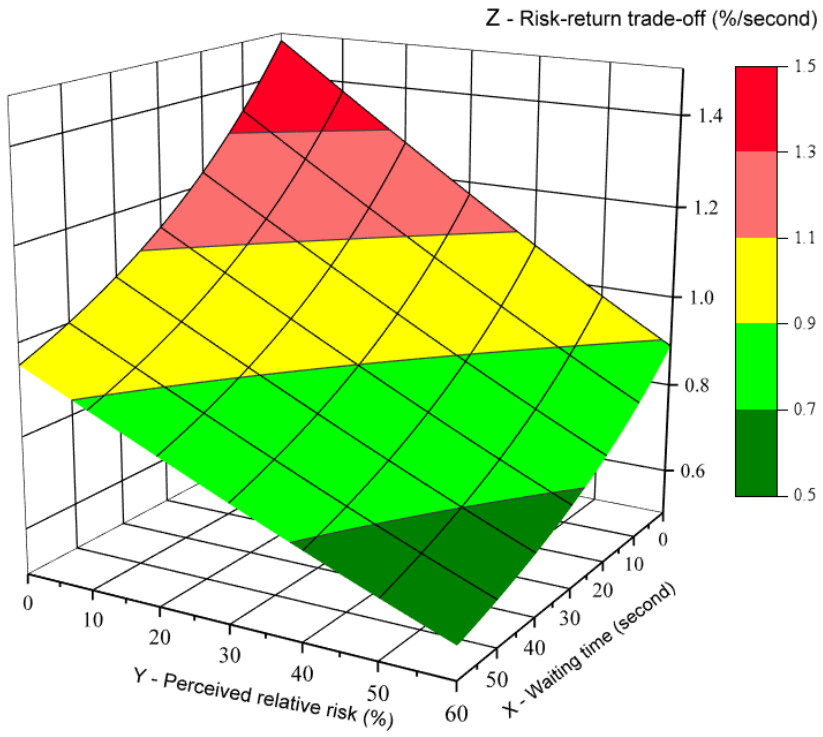


Figure 1. Risk-return rate, perceived safety risk and waiting time

Table 6. Marginal effect of SP attributes

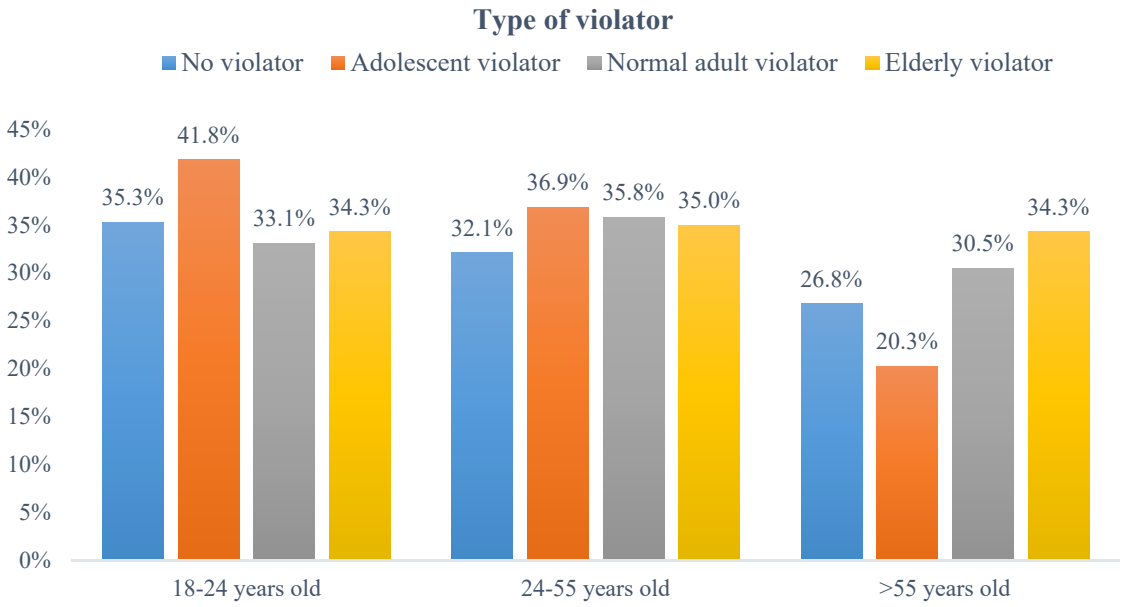
SP attribute	Choice 1: Comply with pedestrian signal	Choice 2: Not comply but wait	Choice 3: Not comply and cross immediately
10% increase in anticipated waiting time for Choice 1	-8.7%	10.0%	0.8%
10% increase in perceived relative risk for Choice 3	1.1%	2.6%	-7.2%

5.2 Situational features

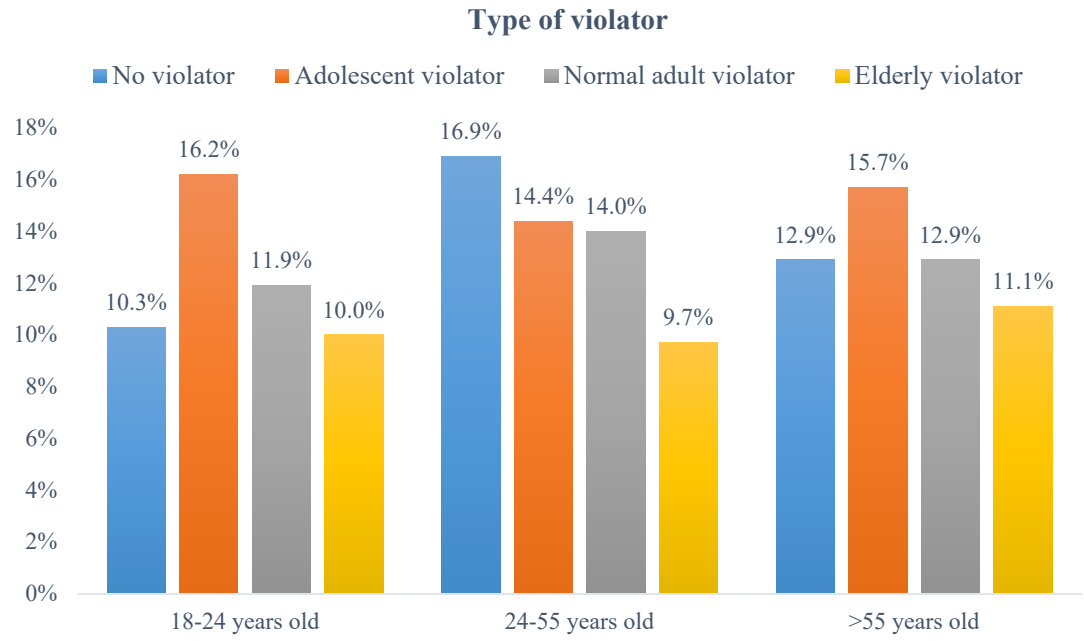
Presence of a violator affects the propensities of red light running violation. For instance, propensities are positively associated with the presence of an adolescent violator. This could be

attributed to the vicarious experience of punishment avoidance as suggested by the deterrence theory (Ellis, 2003). As revealed in previous studies, peoples are more motivated to violate the traffic rules when they see there is another violator (Rosenbloom et al., 2009; Zhu et al., 2021). However, propensities are negatively associated with the presence of an elderly violator. This is because peoples often perceive the red light running violations of elderly as prevalent, regardless of the road environment and traffic conditions. Therefore, the red light running behaviors of elderly could be less instructive (Oxley et al., 1997; Dommes et al., 2013).

Figure 2 depicts the distributions of red light running rates with respect to the age group of respondents and age group of violators (if any). As shown in **Figure 2(a)**, for the respondents who are 18 to 24 years old, red light running rate (Choice 2: not comply but wait for a suitable gap) is the highest when there is an adolescent violator. In addition, for the respondents who are 55 years old or above, red light running rate is the highest when there is an elderly violator. As also shown in **Figure 2(b)**, for the respondents who are 18 to 24 years old, red light running rate (Choice 3: not comply and cross immediately) is the highest when there is an adolescent violator. These could be attributed to the effect of social influence. Peoples tend to follow the behavior of a person who shares the same characteristics, e.g., age (Rosenbloom, 2009; Jay et al., 2020; Kok et al., 2020). However, for the respondents who are 25 to 54 years old, there is no obvious difference in the red light running rate. Nevertheless, such finding indicates that targeted enforcement measures against red light running violation of pedestrians should be imposed at the strategic locations, e.g., schools and elderly homes, where peoples who share the same characteristics may gather.



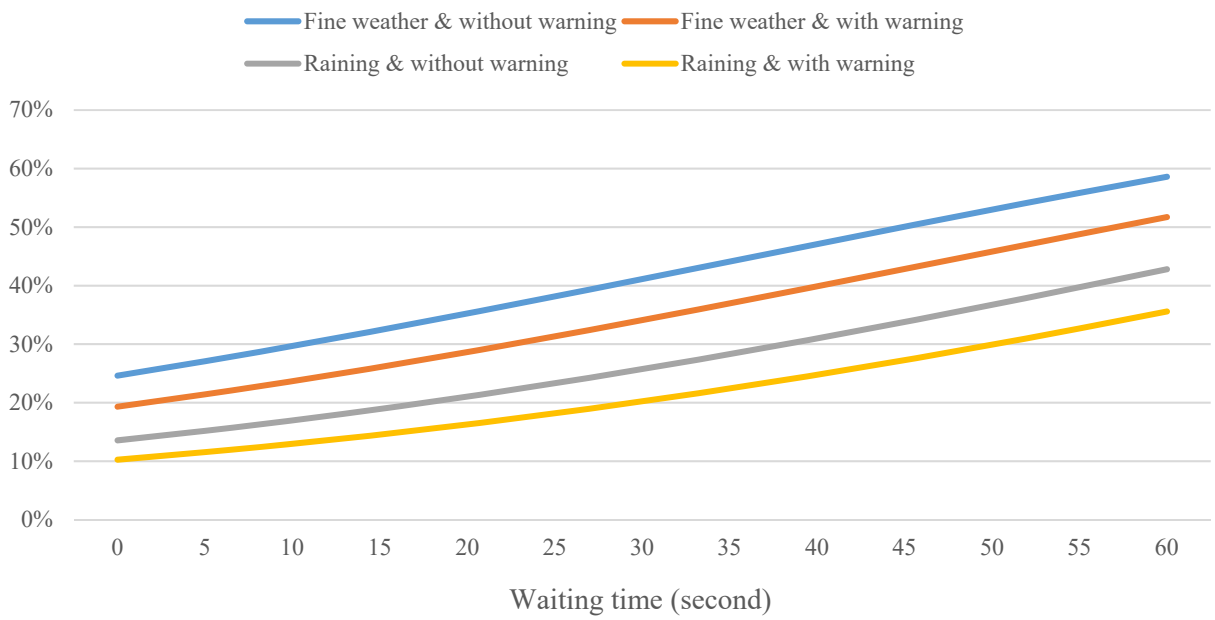
(a) Choice 2



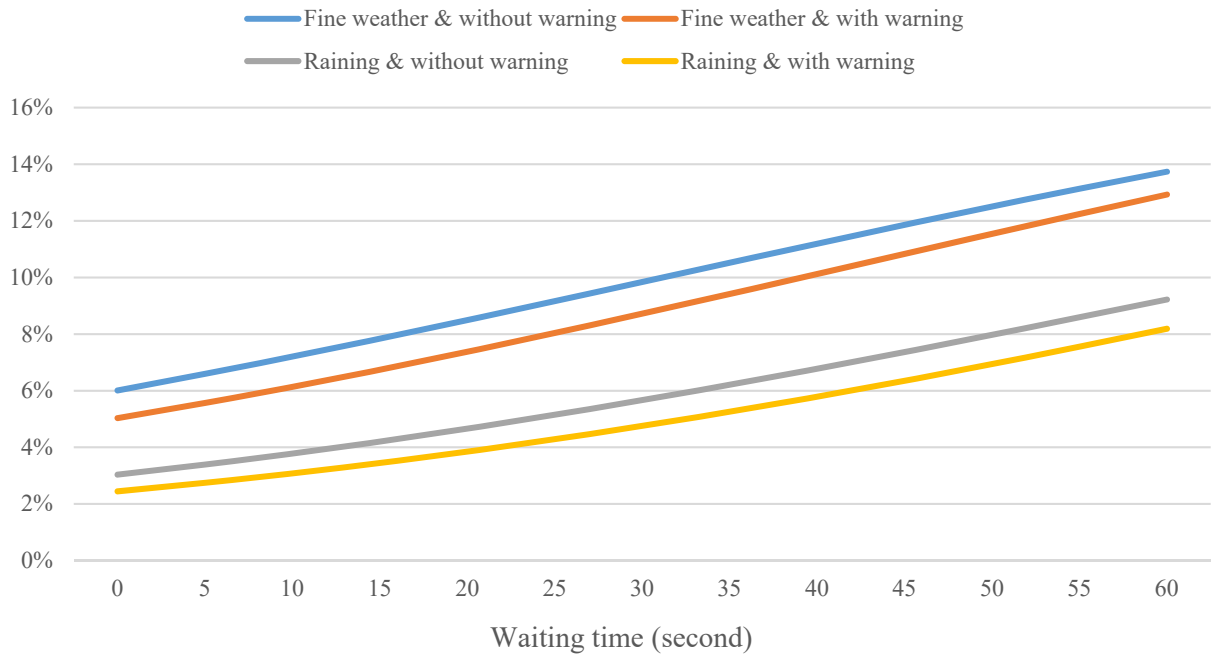
(b) Choice 3

Figure 2. Propensities of red light running violation with respect to presence and type of violator

Figure 3 illustrates the changes in the propensities of red light running violation with respect to waiting time under different scenarios (i.e., raining and presence of warning sign). As shown in **Figure 3**, propensities of red light running violation of pedestrians are lower when there is a warning sign and in the raining condition. Effects of weather condition on the propensities are normally distributed (with standard deviation of 0.57 for Choice 2 and 0.69 for Choice 3 respectively). This implies that only 6.5% (Choice 2) and 3.3% (Choice 3) of respondents would violate the red light in the raining condition. This could be because peoples tend to be risk averse when traveling in the inclement weather conditions (Li and Fernie, 2010). Furthermore, educational level can modify the effect of the presence of warning sign on the propensities. For instance, favorable effect of the presence of warning sign can be magnified for the respondents who have attained the tertiary education or above. This could be attributed to better cognitive performance and safety awareness of peoples who have attained the higher education (Zhang et al.,2016; Liu et al., 2019). Despite that warning signs are installed at the hot spots of pedestrian crashes (i.e., more than five pedestrian injuries per year) in Hong Kong (Transport Department, 2020), it is worth investigating the effectiveness of any innovative solutions, e.g., variable message sign and real-time traffic-actuated signal, in improving the safety awareness of pedestrians in the future study (Liu et al., 2019; Zhao et al., 2020).



(a) Choice 2

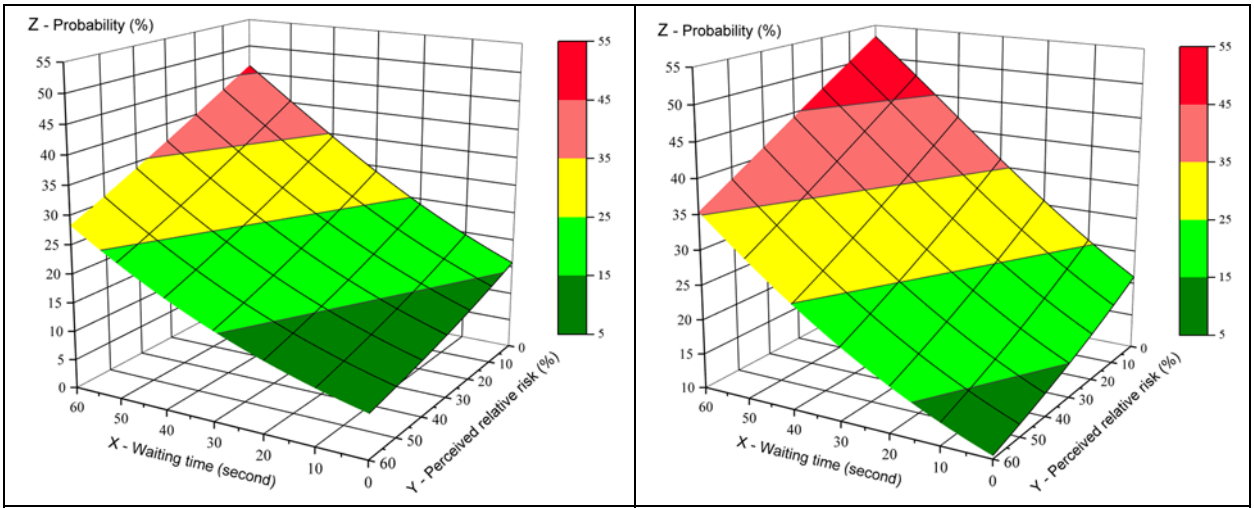


(b) Choice 3

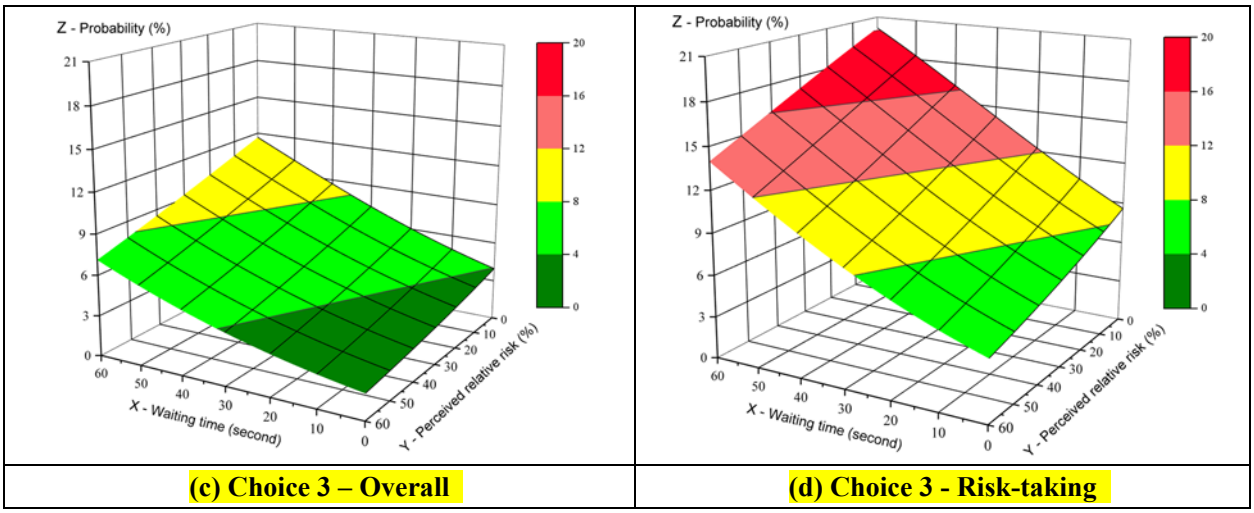
Figure 3. Propensities of red light running violation under different scenarios

5.3. Attitude and personality traits

As suggested by the theory of planned behavior, subjective norms and perceived behavioral control can affect the behavioral intention of individuals (Jiang et al, 2017b; Borhan et al, 2019). As revealed in this study, expectation of family members can affect the propensities of red light running violation of pedestrians (Schwanen and Ettema, 2009). For instance, propensities of red light running violation would increase when one expects that his or her family members also agree with the violation behavior. Such unfavorable effect could be more profound for the respondents who are 18 to 24 years old. On the other hand, propensities of red light running violation are higher for the respondents who have higher perceived behavioral control, lower legal awareness, and are more risk-taking. Moreover, the compound effect (i.e., behavioral control x risk-taking) could be magnified. Such findings are consistent to that of previous studies (Zhou et al., 2016; Wang et al, 2020b). Nevertheless, it is worth investigating the effectiveness of targeted road safety education for the vulnerable road user groups, i.e., adolescents, in improving the safety awareness. **Figure 4** depicts the changes in the propensities with respect to perceived safety risk and waiting time of different pedestrian groups (i.e., risk-taking or not). As shown in **Figure 4(b)** and **4(d)**, propensities of red light running violation of risk-taking pedestrians are higher in general.



(a) Choice 2 – Overall | **(b) Choice 2 - Risk-taking**



(c) Choice 3 – Overall | **(d) Choice 3 - Risk-taking**

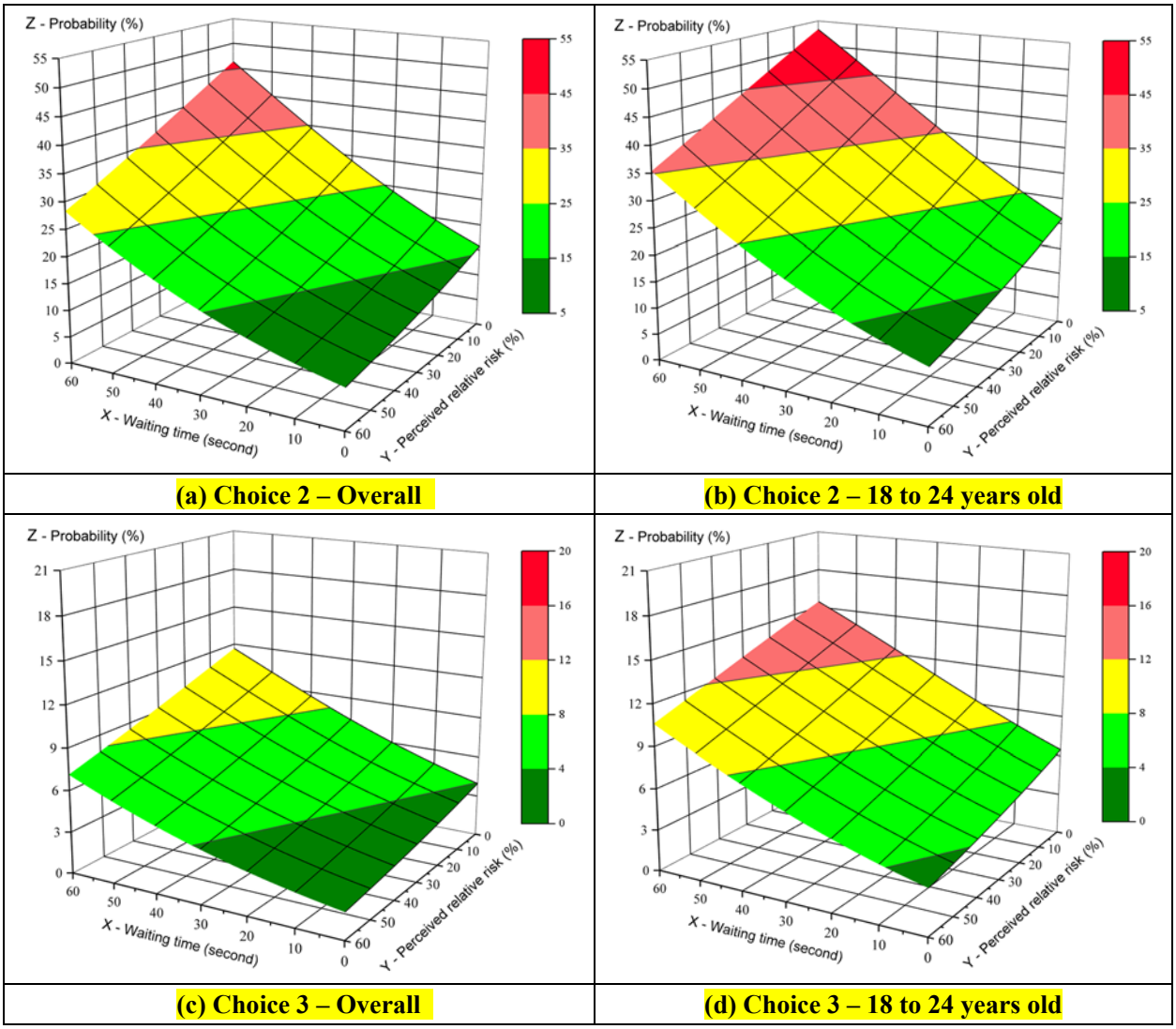
Figure 4. Propensities of red light running violation of different pedestrian groups

5.4 Demographics and socioeconomics

Males and respondents who are 18 to 24 years old have a higher likelihood to violate the red light. However, respondents who have attained higher education have a lower likelihood to violate the red light. Such findings are consistent to that of previous studies (Rosenbloom, 2009; Guo et al., 2011; Brosseau et al., 2013; Zhang et al., 2016; Zhu et al., 2021; Rod et al., 2021). As abovementioned, effects of personality traits and situational features on the red light running propensity can be modified by personal characteristics including age and educational level. This is indicative to the targeted road safety education and promotion strategies. **Figure 5** depicts the changes in the propensities with respect to perceived safety risk and waiting time of different age groups. As shown in **Figure 5(b)** and **5(d)**, propensities of red light running violation of pedestrians who are 18 to 24 years old are higher in general.

In addition, propensities of red light running violation of respondents who have higher monthly income are higher, but that of respondents who possess a driving license are lower. Apparently, peoples are less sensitive to the monetary fine against red light running violations (i.e., HK$ 2,000), as compared to other penalties including driving disqualification (Wong et al., 2008; Li et al., 2014). As suggested by the deterrence theory, individuals' perceptions of sanction are determined by the

severity, certainty and celerity of a punishment (Gibbs, 1985; Kergoat et al., 2017). Above findings imply that it is necessary to increase the certainty of enforcement against red light running violation of pedestrians, particularly at the strategic locations and hot spots of pedestrian crashes (Chen et al., 2020a).



(a) Choice 2 – Overall | **(b) Choice 2 – 18 to 24 years old**

(c) Choice 3 – Overall | **(d) Choice 3 – 18 to 24 years old**

Figure 5. Propensities of red light running violation of different age groups

6. CONCLUSION

In this study, effects of perceived risk, anticipated waiting time, weather condition, presence of violators, and other personal characteristics on the red light running behaviors of pedestrians are investigated using a questionnaire survey. Then, a regret-based multinomial logit model is adopted to analyze the choices between (i) comply with pedestrian signal, (ii) not comply but wait for a suitable gap, and (iii) not comply and cross immediately of pedestrians. Contribution of this study is twofold: First, effects of the trade-off between safety and time, as well as the situational features and personality traits, on the propensities of red light running violation of pedestrians are gauged using a stated preference method. Second, effects of unobserved heterogeneity and correlation between the choices in different scenarios of the same individual are considered using a panel mixed approach.

Results indicate that propensities of red light running violation of pedestrians are positively associated with anticipated waiting time, but negatively associated with perceived relative risk. The safety versus time trade-off of individual can be gauged using the regret-based model. For instance, compliance of pedestrian signal is more sensitive to the change in waiting time than that in safety risk. In addition, situational features including weather condition, presence and type of violator, and presence of warning sign all affect the propensities of red light running violation of pedestrians. Peoples have a higher tendency to run the red light when they see another violator, especially when the violator is an adolescent. Furthermore, males and peoples who are 18 to 24 years old and risk-taking have a higher tendency to run the red light. Such findings should enhance the understanding on the relationship between personal characteristics, choice decision, and red light running behaviors of pedestrians. They are indicative to remedial traffic control measures (i.e., variable message sign and flashing warning sign), enforcement strategies, and targeted road safety education against the red light running behavior of vulnerable pedestrian groups.

Nevertheless, this study is limited to a few alternative-specific variables (i.e., anticipated waiting time and perceived relative risk) only in the SP design. It is anticipated that traffic conditions in

terms of traffic volume, vehicle composition, and vehicular speed can also affect the propensities of red light running violation of pedestrians (Zhu et al., 2021). Hence, it is worth exploring the pedestrians' behaviors in response to the road environments and real-time traffic conditions when more comprehensive behavioral data are obtained using the methods including virtual reality (VR) experiment in the future study. Furthermore, to improve the model performance, a latent model with one RRM and RUM in each segment can be incorporated into a hybrid model structure in the future study.

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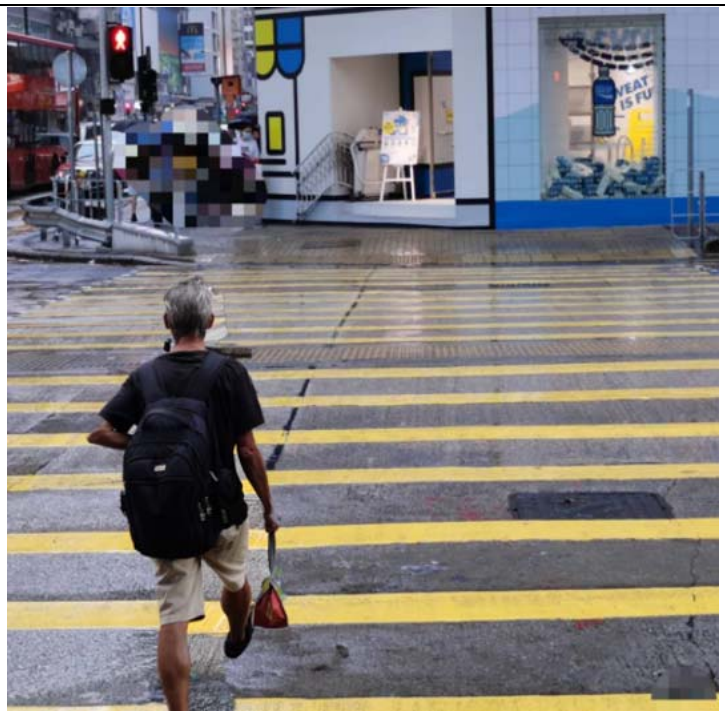
Appendix



Variable	Choice alternative		
	Comply with pedestrian signal	**Not comply but wait for a suitable gap**	**Not comply and cross immediately**
Waiting time	30 second	20 second	0 second
Perceived relative risk	0 %	30%	60%
Weather condition	Raining condition		
Presence and type of violator	An elderly pedestrian is violating the red signal		
Presence of warning sign	No		

Given the scenario (e.g., raining, an elderly pedestrian is violating the red signal, and no warning sign), and waiting time and perceived relative risk for each choice alternative shown above. Which alternative would you choose? (Select one only)

□Comply with pedestrian signal
□Not comply but wait for a suitable gap
□Not comply and cross immediately

Figure A1. Illustration of a stated preference scenario in the questionnaire