Exploring motorcycle red-light violation in response to pedestrian green signal countdown device

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Literature has suggested that angle/rear-end collisions would arise from the reality that motorists and motorcyclists tended to accelerate aggressively in response to the remaining seconds of green signal countdown device (GSCD). One safety concern, while GSCD has gradually been removed for safety in Taiwan, is pedestrian green signal countdown device (PGSCD) that is used by approaching motorists and motorcyclists that may adopt the information to travel aggressively – an unintended consequence that is detrimental to safety. Research has reported that there appeared no negative effect of PGSCD on motorist behaviours but the effect on motorcyclists’ behaviours has been rarely investigated. Using video/speed cameras, the current research investigates motorcyclists’ RLV (red-light violation) behaviours. The descriptive analyses indicate that the percentage of RLV at PGSCD intersection is higher than that at typical intersection, and the violating motorcycles appear to have higher travelling speeds at PGSCD intersection. Several interaction terms were examined with the binary logit framework, and the results reveal that several factors are associated with RLV, notably male/young riders, moped/large motorcycle users, higher approaching speeds of motorcycles, those with tropical helmets, and lower traffic volume. Similar determinants of early-start behaviours (for those waiting at reds and could view the PGSCDs for the crossing pedestrians at the same time) were identified. Implications of the research findings, the concluding remarks, and recommendations for future research are finally provided.

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1. Introduction

1.1. Background

Motorists crossing a signalised junction during the amber phase are in need to determine whether to enter and clear the junction or to make a stop. Such a decision-making process can be affected by a critical part of the signalised junction called the dilemma zone where an individual motorist can neither safely clear the intersection nor make a stop (Institute of Traffic Engineers, 1985). Two main crash types (i.e. angle crashes and rear-end crashes) arise from the uncertainty and complexity of motorist’s decision-making behaviour within the dilemma zone (Ma et al., 2010). One of the commonly adopted approaches to assist motorist’s decision to cross or to stop during the phase transition period (and subsequently to reduce angle/rear-end crashes) is to install vehicular signal with green signal countdown display (GSCD, as shown in Fig. 1). Such device displays the remaining seconds of current signal status to approaching motorists through the synchronisation with the traffic signal controller, which helps motorists make an informed decision – approaching motorists can then take advantage of countdown timing to avoid being trapped in the dilemma zone by either accelerating or decelerating in advance.

The effect of GSCD on traffic safety seems to be controversial despite its better utilisation of the amber time and increased junction capacity. While there has thus far been statistics that show an increase in the number of accidents as a result of such device (due to motorists accelerating aggressively in response to the remaining seconds of GSCD, or decelerating suddenly to avoid being struck in the dilemma zone), such device would be beneficial in assisting old motorists (that tend to have poorer reaction
capability and alertness level) to cross or to stop during the critical phase-change period.

Due to the safety concern over GSCD, many metropolitan cities in Taiwan have removed such device, and red signal countdown display (RSCD) that has a beneficial effect on reducing accidents at junctions is instead recommended (Chen et al., 2007). Another concern over traffic safety, while GSCDs have been gradually removed in Taiwan, is the impact of pedestrian green countdown display (PGSCD), as shown in Fig. 2, on road safety at junctions. Although the PGSCD is to provide pedestrians with the information on the remaining seconds of green signals, the device is visible to all who cross an intersection. While PGSCDs are promoted as a means of improving pedestrian safety at intersections, there are concerns that motorists view PGSCDs when approaching/止 poging at the intersection and use that information to travel more aggressively – an unintended consequence that is detrimental to safety (Brandon and Steven, 2007). To take a car driver approaching the intersection as an example, the driver predicts his/her own red light from the PGSCD for pedestrians travelling in the same direction. Taking advantage of countdown timing, the driver can decide whether to cross the intersection by accelerating or to stop by decelerating in advance. To take a stopping car driver at the intersection as an example, the driver looks to his/her side to see the PGSCD for pedestrians crossing his/her path, and understands that the countdown to a stop signal for the pedestrians predicts a green light for the driver. One can imagine that the closer the waiting driver is to the stop line, the more clear information of PGSCD he/she could obtain to predict a red light.

As shown in Fig. 2, the countdown timing begins as soon as the red phase ends, and counts the green time with a display of an animated/walking green man. Following the green countdown timing that has become zero, the icon “walking green man” turns into a red/still man. As soon as the green timing has become zero, the vehicular signals have a two-second amber interval and then a two-second all-red interval.

1.2. An overview of past studies

A large body of past studies has investigated motorists’ behaviours in response to GSCD. Among these studies, Kidwai et al. (2005) investigating junction efficiency and safety before and after installation of GSCD in Malaysia reported that the device reduced red-light violation (RLV) by about 50%. Lum and Halim (2006) conducting a before-and-after study examined differences in motorists’ responses when approaching a signalised junction with GSCD in Singapore. They reported that there was a 65% reduction in the RLVs within 1.5 months of GSCD installation; and the number of vehicles determining to stop during the amber phase has increased 6.2 times during that period. The effectiveness, nevertheless, tended to dissipate over time as the RLVs bounced back to almost the same level before GSCD installation. They concluded that GSCD would be efficient in helping encourage stopping, but a long-term examination of such device reveals that GSCD would not curb RLVs. Limanond et al. (2010) examined the impacts of GSCD and RSCD on motorists’ behaviours in Bangkok, Thailand. They found that RSCD would help to reduce the start-up lost time at the beginning of the green phase by 22%, and GSCD would reduce the number of RLVs during the beginning of the red phase by 50%.

A study conducted in Taiwan (Chen et al., 2007) specifically investigated the effect of GSCD on junction safety during years 2003–2006 at 187 signalised junction within 1 year before-and-after GSCD installation. Chen et al. (2007) reported that there was approximately a 100% increase in the number of fatal and injury accidents at junctions with GSCDs. They contributed this to the possibility that motorists may tend to accelerate aggressively in response to the remaining seconds of GSCD, thereby increasing the accident risks. Chiou and Chang (2010) subsequently investigated motorists’ responses (including late-stopping ratio, and dilemma zone) to GSCD in Taiwan. Chiou and Chang (2010) reported that although GSCD can reduce late-stopping ratio, the dilemma zone is increased by about 28 m and the decision to cross tended to be more inconsistent among the approaching vehicles, creating a potential risk of rear-end crashes. A study conducted in China by Ma et al. (2010) revealed that GSCD significantly reduced RLVs but increased the risks of collisions with unexpected crossing vehicles or pedestrians due to higher vehicle speeds approaching the junction before the onset of amber phase. Two more recent studies by Long et al. (2011, 2013) in China concluded that GSCD resulted in a higher likelihood of RLV, which is consistent with the studies conducted in Asian countries (e.g. Ma et al., 2010), but contradicts with the studies of flashing green signals in European countries (see, for example, Mahalel et al., 1985; Köll et al., 2004).

While GSCDs have been gradually removed in Taiwan, there has thus far been another concern over traffic safety – the impact of PGSCD on driving behaviours. To improve pedestrian safety at junction, PGSCDs are intended to be used by pedestrians rather than other road users that may view PGSCDs when approaching the junction and use that information to travel more aggressively. There exist relatively few studies that have attempted to investigate the impacts of PGSCDs on motorist behaviours – among the few studies, researchers (see, for example, Eccles et al.,
2004; Markowitz et al., 2006; Huey and Ragland, 2007) have consistently reported that there appeared no negative effect on motorist behaviours (in terms of both speed and RLV) although concerns had been raised that motorists would use PGSCDs to speed up. There exists one study that has specifically investigated the effect of PGSCDs on motorcyclist behaviour in Taiwan (Su and Tang, 2008). Su and Tang (2008) concluded that RLV by approaching motorcycles was found to increase at PGSCD-controlled junctions.

Two studies by Chin and Haque (2010) and Haque et al. (2008) were in attempts to investigate motorcycle exposure as well as the effect of red-light cameras on motorcycle angle collisions in Singapore. These two studies, though not specifically examining the effect of PGSCD, have revealed an important picture of motorcycle behaviours at signalised intersections by reporting that motorcycles tend to accumulate near the stop lines at reds to facilitate an earlier discharge during the initial period of the green. The finding of Chin and Haque (2010) that motorcycles tend to execute an early discharge when waiting at red is important to the current research, as it is not uncommon in Taiwan that the remaining green timing of PGSCD (for crossing pedestrians) can trigger the waiting motorcycles to commit an early-start manoeuvre.

When reviewed together, past studies have provided an important contribution to literature by unravelling that GSCD would be efficient in helping encourage stopping but its effectiveness tended to dissipate over time; and while angle collisions may arise from motorists accelerating aggressively in response to the remaining seconds of GSCD, inconsistent decisions among the approaching vehicles to cross the junction lead to a potential risk of rear-end crashes. Past studies of the impacts of PGSCDs also reported that there appeared no negative effect on motorist behaviours. Despite the informative and insightful results offered by extant studies that have addressed safety problems regarding GSCDs and PGSCDs, many issues have not been thoroughly addressed. For instance, relevant literature seems to be limited in that research efforts tend to be directed towards motorists rather than motorcycles that have thus far dominated traffic in Asian countries such as Taiwan. While in recent years, increasing attention has been directed at investigating motorcycle safety at priority junctions where motorcycle’s right of way is frequently violated (see a review of literature by Pai, 2011), motorcycle safety/behaviour at PGSCD-controlled junctions have not been fully researched yet. That is, a major gap in literature seems to be a lack of knowledge regarding motorcycle safety at PGSCD-controlled junctions where motorcyclists’ decision-making behaviours within the dilemma zone could be more complex than motorists, and consequently angle/rear-end collisions may arise from the possibility that motorcycles may accelerate aggressively in response to the remaining seconds of PGSCD. The present study aims to fill in the major gap of past studies by investigating motorcyclists’ responses to PGSCD at the selected junctions in Taiwan.

The remainder of the current research proceeds with a description of the method used in the current research for a fuller understanding of motorcyclist behavioural patterns at PGSCD-controlled junctions. In this section, research design including how data were collected, selection of locations/participants, the definitions of the examined manoeuvres, and analytical method are described. Research findings, discussion, and implications of the findings are subsequentially provided.

2. Method

2.1. Setting

Using video cameras and speed cameras, the current research employs a videotaping survey that collected the subjects’ two behavioural responses (RLV and early-start behaviours) to PGSCDs. Two parts of survey were conducted in urban area of Taoyuan City, Taiwan: in the first survey, the subjects’ RLV behaviour and speeds were measured/recorded when they were travelling towards the intersections (at intersection A where the subjects were facing PGSCD directly; and at intersection B that is not controlled by PGSCD at all). In the second survey, the subjects were waiting at reds and their early-start behaviours at intersection A (where the subjects were waiting for the red to become green, and meanwhile could see the remaining seconds of PGSCD that are for the crossing pedestrian) and at intersection B (where there is no PGSCD at all) were recorded. We chose the two intersections with the highest number of angle and rear-end crashes involving motorcycles during the prior five years, based on the data from A1AZ national accident database. Table 1 reports the characteristics of these two intersections.

2.2. Data collection

Using video cameras, the present study also collected other data that include, for instance, rider and driver attributes, temporal factors, and vehicle characteristics, all of which are assumed to contribute to motorcyclists’ and motorists’ responses to PGSCDs. All variables including the dependent (i.e. RLV and early-start manoeuvres, and speeds) and independent variables were collected through the video/speed cameras. In the case that the subject was approaching the intersection, the subject was firstly located/observed, and the data such as his/her distance from the stop line, as well as the remaining green time he/she was facing, were obtained. For the subjects whose RLV manoeuvres were observed, their speeds were measured four times at 30, 20, 10, and 0 m away from the stop lines, and were averaged. To avoid being spotted/seen by the subjects and consequently causing a change in crossing behaviours (i.e. more compliant with the speed limits), the four speed cameras were camouflaged by human observers’ clothes. Using wireless interphone the human observer measuring the speed at 30 m away from the intersection had to inform the other three observers of which vehicle being located for speed data collection. In the case that there were multiple motorcycles approaching the intersections, the subject was randomly selected from the groups. The authors admit that possible bias may arise from the case that one subject was randomly drawn from the multiple motorcycles/cars approaching the intersections.

Table 1
The characteristics of the three intersections selected.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>PGSCD</th>
<th>Roads</th>
<th>Speed limits</th>
<th>Arms</th>
<th>No. of lanes</th>
<th>Road width</th>
<th>A red (s)</th>
<th>Amber (s)</th>
<th>Green phase (s)</th>
<th>All red (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>With PGSCD</td>
<td>Chai-Shou Rd. and Samin Rd.</td>
<td>50 km/h</td>
<td>4-arm</td>
<td>2</td>
<td>16.5</td>
<td>100</td>
<td>2</td>
<td>45</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>Without PGSCD</td>
<td>Wen-Zong Rd. and Lung-Shou St.</td>
<td>50 km/h</td>
<td>4-arm</td>
<td>2</td>
<td>15.8</td>
<td>105</td>
<td>2</td>
<td>65</td>
<td>2</td>
</tr>
</tbody>
</table>
Fig. 3. A schematic illustration of the three video cameras installed.

Nonetheless, with the restricted funds and manpower, these are the best data that could be obtained.

As for the dependent variable (outcome variable), three video cameras were installed to capture the information needed (see Fig. 3 for a schematic illustration of the three cameras installed). The camera A was installed in the upstream and was pointed towards the intersection, capturing the information such as the presence of a pillion passenger, rider attributes, motorcycle’s number of plate, and traffic volume. The camera B placed in the downstream (the first stop line) was pointed towards the approaching/stopping subject, capturing the information such as the presence of a pillion passenger, rider attributes, and traffic volume. The camera C was installed in the second stop line and facing the intersection. Three cameras would enable the subjects’ behaviours at the selected intersections to be more accurately captured. To avoid being spotted/seen by the subjects and consequently causing a change in crossing behaviours (i.e. more compliant with the red lights), the three video cameras were well hidden behind fixed objects such as trees or telegraph poles. Regarding the independent variables, a majority of independent variables can be readily captured using the video cameras – for example, vehicle characteristics. It is worth pointing out here that it can be a challenge to identify rider attributes (e.g. rider age/gender; motorcycle engine size) through the use of video cameras. Drivers’ attributes (age/gender) were not measured, as it is impossible to identify car drivers’ age and gender through the windscreens when manually observed from the video clips. It is thought that the identification of motorcycle engine size can be less of a problem as the current classification for motorcycle engine sizes in Taiwan is by the colours of number plates – green and white plates represent two ranges (i.e. green for motorcycles with engine size 50cc or below; and white for 51cc–250cc, respectively), while yellow and red plates are for those with 251cc–550cc, and 551cc or above, respectively. With regard to rider’s age/gender, the rider’s appearance (e.g. garment, helmet, hair length, figures) that was recorded by video cameras provides a basis for judging the subject’s age/gender. A combination of the three video cameras is expected to more accurately capture these rider attributes (e.g. age/gender, engine size).

The two intersections with the highest number of angle and rear-end crashes involving motorcycles during the prior five years (based on the data from A1/A2 national accident database) were selected for conducting the videotaping survey. Due to limited funding and time required for manpower, the current research is not able to investigate possible variations in motorcyclists’ and drivers’ behaviours across various roadway/traffic conditions. With additional allowance in funding and time, future research, nonetheless, may attempt to extend the current research by examining the effects of roadway/junction attributes (e.g. junction area, number of arms, and duration of amber/all-red timing) on the subjects’ behaviours.

The videotaping survey was conducted by the well-trained research assistants at two time periods (peak hours: 0700–0900/1700–1900; off-peak hours: 0901–1659) for 2 years (throughout the years 2012–2013). Observations during evening/night hours, and under adverse weather condition (e.g. raining), were not conducted as a result of the difficulties with identifying rider/vehicle attributes. White stripes were marked at 10-m intervals for determining the distances from specific motorcycles/cars that were approaching the junctions (laser speed cameras were also used for helping measure the distance). Following the green countdown timing that has become zero, a two-second amber interval and two-second all-red interval follow. When analysing the effect of the remaining green timing on the subjects’ behaviours, the two-second amber interval is included in the green countdown. The main reason for combining amber time with green time is because drivers and riders would take advantage of amber time and decide to cross the junction even after the green countdown timing has become zero. The green time in the current research, as a result, is defined as green time + amber time.

As for the selection of participants, since this is a videotaping study, in survey part 1, all motorcycles (including all sorts of motorcycles but excluding bicycles, electric motorcycles/bicycles) and cars (including sedans, taxis, and buses/coaches) travelling
through the two selected intersections were the subjects. It is worth pointing out here that past research (Haque et al., 2008; Chin and Haque, 2010) has reported that motorcycle riders tend to weave through the traffic and accumulate beyond the stop line. This group of riders was not counted as RLV riders as the current research focuses on the motorcycles approaching the intersections without being restricted by other stopping vehicles (for survey 1).

In survey part 2, all motorists waiting for the green phase at area A (i.e. hook-turn area that is an engineering measure designed for left-turn motorcycles coming from the left-hand direction on the cross road, as illustrated in Fig. 3) were observed; and car drivers in area B (i.e. inner lane where motorcycles, except for large heavy motorcycles, are prohibited from travelling on it) were also included. Those waiting for the green phase in areas C (i.e. an area designed for separating motorists and cyclists from mixed traffic and helping them to have a shorter start-up delay than cars) and D (i.e. outer lane, as reported in Fig. 3) were excluded from the study as their early-start manoeuvre become impossible due to being blocked by the traffic ahead (i.e. those waiting in areas A and C).

### 2.3. Definitions of red-light violation and early-start behaviours

The definitions of RLV are those who were approaching the intersections and had completed crossing the intersections when the signal was red. The cases in which the riders stopped downstream the stop lines, such as on the zebra crossing, or at some points within the intersections, were also identified as red-light violators.

Early-start ones include those who were initially waiting at reds, and subsequently executed the early-start manoeuvres before the reds turned into green phase. It should be noted here that there exist cases where the subjects were observed to initiate early-start manoeuvres, but stopped at some points within the intersections (i.e. after the stop line). These cases were counted as early-start manoeuvres as they were still considered as illegal crossers that would therefore lead to angle/rear-end crashes.

### 2.4. Analysis

All data collected were entered into the Excel spreadsheet, and SPSS 22 (IBM) was used for data analysis. Motorcyclists’ RLV behaviours were firstly compared to car drivers through descriptive statistics taking into account the distance from the subject to the stop line, and whether the PGSCD was present. A comparison of speeds was also made for those executing RLV behaviours at intersections with/without PGSCDs. Since motorcyclists’ behavioural patterns in response to PGSCDs are the primary focus of the research, the association between riders’ RLV and other variables was then examined using the binary logit model (a thorough derivation of the model is provided in several well-known textbooks, notably, Hosmer and Lemeshow, 2000).

Next, the percentage of early-start manoeuvre by motorcyclists was compared with that of car drivers, taking into account the presence of PGSCDs and the remaining seconds of red and green timing. A binary logit model was then estimated to investigate the influential factors on motorcyclists’ early-start behaviour at PGSCD intersection.

### 3. Results

#### 3.1. Survey 1: RLV

Descriptive statistics on the RLV ratio and speeds by the subjects (motorcycles and cars) are reported in Tables 2 and 3. As reported in Table 2, the RLV ratio at the junction with PGSCD is higher (especially for those riders that are closer to the stop line). This can be an indication of the possibility that the riders closer to the stop line were more likely to ignore the red lights, and such an effect is more pronounced at the junction with PGSCD. The result is interesting, as it does not concur with past studies (see, for example, Lum and Halim, 2006; Chiou and Chang, 2010) that investigated motorists’ behaviours in response to GSCDs – motorists were not observed to have such a behavioural pattern. The finding, however, is partially in line with the study of Su and

<table>
<thead>
<tr>
<th>Distance from the stop line as red phase begins (m)</th>
<th>0–10</th>
<th>11–20</th>
<th>21–30</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>With PGSCD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of RLV vehicles</td>
<td>163</td>
<td>80</td>
<td>25</td>
<td>268</td>
</tr>
<tr>
<td>Percent of RLV</td>
<td>24.51</td>
<td>15.72</td>
<td>7.20</td>
<td>17.62</td>
</tr>
<tr>
<td>Average speed of RLV vehicles</td>
<td>52.2</td>
<td>53.9</td>
<td>54.7</td>
<td>54.6</td>
</tr>
<tr>
<td>Total number of vehicles</td>
<td>665</td>
<td>509</td>
<td>347</td>
<td>1521</td>
</tr>
<tr>
<td><strong>Without PGSCD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of RLV vehicles</td>
<td>187</td>
<td>99</td>
<td>37</td>
<td>323</td>
</tr>
<tr>
<td>Percent of RLV</td>
<td>27.5</td>
<td>17.58</td>
<td>8.47</td>
<td>19.23</td>
</tr>
<tr>
<td>Average speed of RLV vehicles</td>
<td>51.8</td>
<td>52.7</td>
<td>53.1</td>
<td>52.2</td>
</tr>
<tr>
<td>Total number of vehicles</td>
<td>680</td>
<td>563</td>
<td>437</td>
<td>1680</td>
</tr>
</tbody>
</table>
Tang (2008) that has reported that motorcyclists tended to accelerate more aggressively in response to PGSCDs. Likely reason for the disparity between car drivers and motorcycle riders is that motorcycles are more manoeuvrable and outperform other motorised vehicles in terms of accelerating in urban environments, thereby being more likely to travel more aggressively at PGSCDs.

It is also noteworthy that the average speed of the violating motorcycles is higher at PGSCD. Accidents that result from motorcycle's RLV manoeuvre and the resulting high velocities can be devastating in terms of accident consequence. The findings here, although through a simple descriptive analysis, underscore the importance of enforcement on both motorcycle's RLV behaviour and controlling motorcycle speed at intersections with PGSCDs.

Car drivers appear to exhibit similar behavioural patterns to those by motorcycle riders (see Table 3). Closer distance from the car drivers to the stop lines was a trigger point, in spite of a lower probability of RLV compared with motorcycle riders.

The current study estimates the binary logit model of riders' RLV at intersection with PGSCD, and the model estimation results are reported in Table 4. Looking at the specific results in Table 4, it appears that male riders were more likely than female riders to commit RLV behaviours. As for the young-rider effect, young riders were more likely to neglect the red light, and the result can be explicative if one appreciates that young riders in general tend to have risk-taking road behaviours (leading to an increased likelihood of RLV manoeuvres). Traffic volume was found to be an important indicator of riders' RLV manoeuvres. In the current research, traffic volume is defined as the number of motor vehicles (including all motorised vehicles, but excluding non-motorised vehicle such as bicycles) that crossed/arrived the intersection during the time of the red/green light cycle when the vehicle/ motorcycle arrives. The data were collected/estimated by observing the videotaping footages. Traffic volume data were categorised as low (<15/min), medium (15–30/min), and high (>30/min). Only the cross-traffic volume appears to be statistically significant in the model, and an increased likelihood of RLV manoeuvres was found to be associated with low traffic volume (<15/min).

The presence of pillion passenger may play a part in the likelihood of RLV manoeuvres – the parameter estimate of the indicator is negative. It indicates that riders carrying pillion passengers were less prone to execute RLV manoeuvres, which may be a reflection of the possibility that a motorcycle with a pillion passenger may not be operated as easily/stably as that without a passenger, resulting in the operator (rider) complying with the red light more often. Another possible reason is that the rider may behave more safely out of a sense of responsibility for the passenger's safety.

It deserves further interpretation regarding the effect motorcycle engine size has on the likelihood of RLV manoeuvres – the estimated parameters for the indicators for two engine-size ranges (green number plate: 50cc or below; and red number plate: 551cc or above) appear to play a role in the manoeuvre. The parameters for those with engine size of 50cc (moped) or below and 551cc or above (large heavy motorcycle) appear to be positive, implying that those riding mopeds/scooters and large heavy motorcycles were more likely to commit RLV behaviours.

The model results also show that riders facing the longer remaining seconds of green signals and travelling at higher speeds were more likely to have RLV behaviours. On the contrary, the parameter for the distance from the subject to the stop line appears to be negative, suggesting that riders far from the junction were more likely to stop.

On the contrary to standard helmets that fully cover motorcycle riders' heads from skull to chin, as well as with a chin bar and visor, tropical helmets that are commonly used in tropical countries protect riders' skulls only. This type of helmet, compared to standard helmets, is more affordable (as cheap as 3US), and thus is commonly adopted by riders on small motorcycles such as mopeds and scooters (Yu et al., 2011). Standard helmets, on the other hand, are much more expensive, and are more common to those on heavy motorcycles that tend to be ridden for inter-city travel. Helmet style was found to be a contributory factor to the RLV behaviour. The estimated parameter for the indicator variable “tropical helmet” is positive, indicating that riders with tropical helmets tended to execute RLV behaviour. The finding revealed by the parameter “tropical helmet” may capture the interactional effects of engine size, rider age, and experience. That is, full-cover helmets that are commonly used for those travelling with heavy motorcycles whose riders can be more experienced, while tropical helmets covering only the upper part of head are generally adopted by moped users who are in general young and less experienced. On the contrary to users of heavy motorcycles being more likely to approach the PGSCD-controlled intersections more carefully.

### Table 4

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter estimate</th>
<th>OR</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-2.122</td>
<td>-</td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for male rider</td>
<td>0.176</td>
<td>1.19</td>
<td>1.06–1.35</td>
<td>0.002</td>
</tr>
<tr>
<td>Indicator variable for young rider</td>
<td>0.289</td>
<td>1.34</td>
<td>1.07–1.66</td>
<td>0.005</td>
</tr>
<tr>
<td>Indicator variable for traffic volume (&lt;15 per min)</td>
<td>0.315</td>
<td>1.37</td>
<td>1.06–1.77</td>
<td>0.008</td>
</tr>
<tr>
<td>Indicator variable for large heavy motorcycle (551cc or above)</td>
<td>0.336</td>
<td>1.40</td>
<td>1.06–1.85</td>
<td>0.009</td>
</tr>
<tr>
<td>Indicator variable for moped (50cc or below)</td>
<td>0.260</td>
<td>1.30</td>
<td>1.07–1.57</td>
<td>0.007</td>
</tr>
<tr>
<td>Indicator variable for tropical helmet</td>
<td>0.351</td>
<td>1.42</td>
<td>1.09–1.85</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for off-peak hours</td>
<td>0.338</td>
<td>1.40</td>
<td>1.16–1.70</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for the presence of pillion passenger</td>
<td>-0.186</td>
<td>0.83</td>
<td>0.72–0.96</td>
<td>0.007</td>
</tr>
<tr>
<td>Remaining green time (s)</td>
<td>-0.285</td>
<td>1.33</td>
<td>1.14–1.49</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Vehicle's distance from the stop line (m)</td>
<td>-0.299</td>
<td>0.74</td>
<td>1.12–1.57</td>
<td>0.003</td>
</tr>
<tr>
<td>Vehicle approaching speed (km/h)</td>
<td>0.360</td>
<td>1.43</td>
<td>1.06–0.91</td>
<td>0.004</td>
</tr>
<tr>
<td>Young rider and tropical helmet</td>
<td>0.329</td>
<td>1.39</td>
<td>1.15–1.67</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Large heavy motorcycle (551cc or above) and off-peak hours</td>
<td>0.387</td>
<td>1.47</td>
<td>1.16–1.87</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Moped and remaining green time (s)</td>
<td>0.429</td>
<td>1.54</td>
<td>1.13–2.08</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Summary statistics

Observations: 1521 (1253 observations for “not RLV” cases; 268 observations for “RLV” cases)
Restricted log-likelihood (constant only): -1226.8
Log-likelihood at convergence: -968.0
\( \sigma^2 = 0.211 \)
tropical-helmet users that can be young and inexperienced moped riders may have higher tendency to commit risky manoeuvres such as RLV behaviours in response to PGSCDs.

3.2. Survey 2: early-start behaviour

The aim of the survey 2 is to examine whether the subjects (while waiting at red) would make the use of the remaining green timing of PGSCD (for the crossing pedestrians) to execute early-start manoeuvres which would cause conflicts with the crossing pedestrians and cars. To serve as a comparison, riders’ and drivers’ early-start behaviours at intersections A (with PGSCD) and B (without PGSCD) were recorded, respectively.

Figs. 4 and 5 report the early-start (between second –1 and –4) and late-start manoeuvres (between second 1 and 4) by motorcycle riders and car drivers, respectively. A careful observation on Fig. 4 shows that, during all-red period (between second –1 and –2), the percentage of early-start manoeuvres by motorcyclists at intersection A (with PGSCD) appears higher than that at intersection B (without PGSCD). This implies that motorcyclists while stopping were likely to take the use of the remaining seconds of PGSCD for executing early-start manoeuvres. On the other hand, Fig. 4 also shows that, between second –3 and –4 (i.e. amber for the cross traffic; red for the observed subjects), PGSCD seems to play a trigger role in encouraging riders to execute early-start manoeuvres – the percentage of early-start manoeuvres while travelling through the intersection with PGSCD appears higher than that without PGSCD. It shows that PGSCD also has a similar effect on car drivers’ tendency of early-start manoeuvres, though with a less pronounced effect (see Fig. 5).

The current study estimates the binary logit model of riders’ early-start manoeuvres at intersection with PGSCD, and the model estimation results are reported in Table 5. Similar to the RLV model (see Table 4), young and male riders appear to have higher tendencies for early-start manoeuvres. Other factors that are associated with an increased likelihood of early-start manoeuvres include those riding scooters/large heavy motorcycles, during off-peak hours, those wearing tropical helmets, and when the crossing traffic volume was low (<15/min). Riders who arrive at the intersection with longer countdown times on the PGSCD (for the crossing pedestrians) and travelling with pillion passengers were less likely to commit early-start behaviours.

4. Discussion and conclusions

The current research investigates motorcyclists’ behavioural patterns by classifying RLV behaviours into two manoeuvres: RLV and early-start manoeuvres. These motorcyclists’ behavioural patterns are compared with those by car drivers at intersections with and without PGSCDs. The results indicate that there is prevalence of RLV and early-start manoeuvres at PGSCD-controlled intersection both for motorcyclists and car drivers, and the effect of
PGSCD appears more pronounced for motorcyclists. Motorcyclists’ speeds when executing RLV manoeuvres at intersection with PGSCD are higher than those at intersection without PGSCD, which would indeed result in more devastating crash impact once a crash has occurred.

When considering interventions that curb motorcyclists’ RLV behaviours at PGSCD-controlled intersections, the font size of the PGSCD remaining time can be considered to reduce, and re-positioning PGSCD should also be well planned. This is to prevent approaching motorcyclists from easily viewing/capturing the information on PGSCD and consequently executing risky behaviours such as RLV manoeuvres. The PGSCD font size, however, should be adjusted appropriately to ensure that pedestrians’ ability to view it should not be compromised.

A reduced font size of PGSCD could be effective to reduce RLVs by preventing drivers from reading the PGSCDs that are on the far side of an intersection they are approaching (or are stopped at, but well back from the stop line). The approach, nonetheless, would not help much to prevent early starts by looking sideways at PGSCDs for the cross street, because the riders/drivers would be closer to the PGSCD than the pedestrians who need to see it. An alternative approach “blinders” that have been adopted in western countries (e.g. in London’s King Cross area) can be considered – the design, that prevents drivers from seeing pedestrian signals, makes the lights visible only to people who are directly opposite to the lights.

Using two binary logit models, the present paper also specifically examines the determinants of motorcyclists’ RLV and early-start manoeuvres at intersection with PGSCD. Significant variables associated with these two risky manoeuvres include young and male riders, moped and large heavy motorcycle users, off-peak hours, those wearing tropical helmets, and when cross-traffic volume was low.

To obtain more insights into the contributory factors, the current research estimates a typical binary logit framework with numerous interaction terms. The young-rider variable was used as interactions with the other variables. The interaction term “young riders with tropical helmets” appear to be significant, suggesting that this certain young group travelling with tropical helmets was more likely to commit RLV and early-start manoeuvres at PGSCD-controlled intersections. It has been established in literature (see, notably, Yu et al., 2011) that standard helmets perform better than half-coverage helmets (such as tropical helmets) in reducing head/brain injuries, and a question survey commissioned by Li et al. (2008) reported that a majority of the public were aware of the advantage of standard helmets. It is possible that, for the current research, riders who wear tropical helmets are less concerned with safety, and they show that same lack of concern by committing violations (and such an effect seems more pronounced on young riders).

The interaction effect of motorcycle engine size with temporal factor yields some interesting results – the interaction term “large heavy motorcycles and off-peak hours” results in an increased likelihood of RLV manoeuvres. Such a result is reasonable due to lower traffic volume during off-peak hours and/or greater power output of machines. The interaction term “moped” and “the remaining green time” appears to a significant determinant of RLV manoeuvre, implying that, with an increase in the remaining green time, moped riders were more likely to commit RLV manoeuvre. Riders who were farther away from the intersection at a particular time (e.g. 10 s before the lights change) were more likely to commit a RLV than those who were closer, and the possible reason is because the closer riders have sufficient time to cross the intersection before the light changes. The effect appears to be more pronounced on moped riders. Such a finding is important when considering relevant intervention, as A1AZ national accident data shows that mopeds were over-represented in angle crashes at signalised intersections. Police enforcement and education efforts may be directed towards this certain group of motorcycle riders to ensure their safety particularly at PGSCD-controlled intersections.

Another interaction term “moped and peak hours” results in an increased likelihood of early-start manoeuvre. A likely reason for this result is that mopeds riders when waiting at red may take advantage of the traffic that is heavily congested during rush hours (with slower traffic speed), and their greater manoeuvrability (when compared with larger machines) subsequently enable them to identify a gap among the traffic across the intersection.

High travelling velocities can be anticipated while executing RLV manoeuvres, and as a result, the resultant collision impact can be far more threatening. Safety strategies such as controlling motorcycle speed that aim to increase motorcycle conspicuity and reduce car drivers’ speed/distance judgement error (thereby reducing right-of-way accidents) have been well documented in literature (see, notably, Pai, 2011; Pai et al., 2013). Similarly, controlling motorcycle speed when approaching the PGSCD-controlled intersections may constitute an effective countermeasure for reducing collision impact, and also for allowing more time for last-minute manoeuvring and braking in moments before impact. Engineering techniques that have been adopted for speed

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter estimate</th>
<th>OR</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-1.557</td>
<td>-</td>
<td>1.07–1.41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for male rider</td>
<td>0.205</td>
<td>1.23</td>
<td>1.07–1.48</td>
<td>0.026</td>
</tr>
<tr>
<td>Indicator variable for young rider</td>
<td>0.231</td>
<td>1.26</td>
<td>1.07–1.48</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for traffic volume (≤15 per min)</td>
<td>0.257</td>
<td>1.29</td>
<td>1.08–1.55</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for large heavy motorcycle (551cc or above)</td>
<td>0.369</td>
<td>1.45</td>
<td>1.16–1.80</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for moped (50cc or below)</td>
<td>0.199</td>
<td>1.22</td>
<td>1.08–1.38</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Indicator variable for tropical helmet</td>
<td>0.267</td>
<td>1.31</td>
<td>1.08–1.57</td>
<td>0.011</td>
</tr>
<tr>
<td>Indicator variable for off-peak hours</td>
<td>0.250</td>
<td>1.28</td>
<td>1.10–1.50</td>
<td>0.016</td>
</tr>
<tr>
<td>Indicator variable for the presence of pillion passenger</td>
<td>-0.167</td>
<td>0.85</td>
<td>0.73–0.98</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Remaining green time (s)</td>
<td>-0.282</td>
<td>0.75</td>
<td>0.62–0.91</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Young rider and tropical helmet</td>
<td>0.271</td>
<td>1.31</td>
<td>1.02–1.68</td>
<td>0.033</td>
</tr>
<tr>
<td>Moped (50cc or below) and peak hours</td>
<td>0.246</td>
<td>1.28</td>
<td>1.05–1.56</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Summary statistics
Observations: 3367 (2109 observations for “not early-start” cases; 1258 observations for “early-start” cases)
Restricted log-likelihood (constant only): -1582.2
Log-likelihood at convergence: -1120.6
σ² = 0.292
management in Taiwan include traffic calming (e.g. speed hump, rumble strip). These engineering measures are commonly used for controlling cars’ speeds, and can be considered for motorcycle speed management at PGSCD intersections. In recent years there have been deployments of speed cameras that are specifically targeting motorcycle traffic both on undivided roadways and at intersections.

While the present research has established the effect of PGSCD on the two RLV types, and uncovered the determinants of riders’ RLV and early-start manoeuvres (that have not been investigated in past studies), future research may attempt to examine other unmeasured factors (e.g. other socio-economic attributes, riders’ experience in riding motorcycles, getting involved in accidents previously, being prosecuted for RLV, and familiarity with the intersections/signals) on RLVs. In addition, due to the prohibitive costs of a larger scale of videotaping survey, various intersection alignments and other traffic attributes that may play a part in contributing to these two risky manoeuvres cannot be studied. The collection and use of more detailed data could provide important additional insights – for instance, it would be interesting to examine the characteristics of motorcyclists’ risky manoeuvres/behaviours in other jurisdictions. This is because the empirical results obtained may be unique to Taoyuan County – the extent to which the findings pertain to other jurisdictions/intersections where there are, for instance, differences in the durations of amber/all-red timings is unclear. Further work may conduct additional analyses using data from other jurisdictions/other intersections to ascertain whether the contributing factors uncovered in the present paper are salient to these two risky manoeuvres.

Finally, it is worth pointing out that the present paper relies on videotaping and manually tracking and recording crossing behaviours, which requires intensive labour demands. Further research may adopt advanced traffic information collection systems (e.g. an image processor capable of simultaneously tracking and recording the dynamics of individual vehicles) that have been applied in past studies (see, notably, Köll et al., 2004; Lum and Halim, 2006).

Acknowledgements

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References