COUNTDOWN PATTERNS AND STARTUP BEHAVIOR AT SIGNALIZED INTERSECTIONS

Wisinee WISETJINDAWAT\(^1\), Motohiro FUJITA\(^2\), Koji SUZUKI\(^3\) and Hiroyuki MIYAZAKI\(^4\)

\(^1\)Member of JSCE, Assistant Professor, Dept. of Civil Eng., Nagoya Institute of Technology (Gokiso, Showa, Nagoya 466-8555, Japan)
E-mail: wisinee@nitech.ac.jp

\(^2\)Member of JSCE, Professor, Dept. of Civil Eng., Nagoya Institute of Technology (Gokiso, Showa, Nagoya 466-8555, Japan)
E-mail: fujita.motohiro@nitech.ac.jp

\(^3\)Member of JSCE, Associate Professor, Dept. of Civil Eng., Nagoya Institute of Technology (Gokiso, Showa, Nagoya 466-8555, Japan)
E-mail: suzuki.koji @nitech.ac.jp

\(^4\)Non Member of JSCE, Kamo Civil Eng. Division, Gifu Prefectural Government (2610-1 Shimokobi, Kobi-cho, Minokama City, Gifu 505-0035, Japan)
E-mail: miyazaki-hiroyuki@pref.gifu.lg.jp

A countdown timer can reduce startup delays and improve queue discharge; however, many researchers have reported an increased occurrence of red light violations with the use of such timers. We conducted an experiment to examine whether it is possible to retain the benefits of the countdown timer while limiting the problem of red light violations at startup when the signal switched from red to green. This experiment investigated the impacts of different settings of the countdown timer (10 different patterns for timer display) and without the timer on drivers (mainly young male drivers) and on two types of vehicles (with and without the idling stop system). We determined their influences on the startup delay and the proportion of red light violations at startup. Based on the findings, the extent of the reduction in startup delay is more apparent for vehicles with the idling stop system. In the presence of the countdown timer, drivers with the idling stop system responded 65% quicker than in the absence of the timer. The pattern that had the best overall performance in reducing startup delay without increasing drivers’ tendency to violate red lights at startup, was to count down by seconds, then to stop the timer and keep the number unchanged for a short period (approximately 3 seconds) before the green phase. These findings may benefit the implementation or modification of countdown-signalized intersections to improve the safety of crossing pedestrians as well as driver satisfaction.

Key Words: countdown timer, driver behavior, startup delay, premature start

1. INTRODUCTION

In recent years, the countdown timer, which is one of the traffic light change anticipation systems (TLCAS), has been increasing in popularity in many Asian countries. The development of TLCAS began with a flashing signal phase in which the signal of the current color is flashed (or sometimes the color of the next phase is flashed simultaneously with the current phase color) for a few seconds before the onset of the next signal phase. This is done to alert drivers of the upcoming phase change\(^5\). The work of Koll et al.\(^2\) is an example of research on the real-world application of the flashing signal system. Driver behavior with and without the flashing green before the amber light was analyzed based on surveys at 10 locations in Switzerland, Austria, and Germany. However, the results showed that the flashing green phase had an unsatisfactory effect. This was due to the fact that the flashing green phase widened the time period when drivers were indecisive, resulting in an increase in the number of early stops as drivers tended to underestimate the duration remaining until the end of the amber light. This increase in early stops led to an increase in rear-end collisions.

A more recent version of TLCAS is the signal
phase countdown system in which the time remaining is shown as a number in seconds until the onset of the upcoming signal phase displayed together with the current signal light. This technique provides not only the remaining phase time to drivers but also the exact timing when the upcoming phase will occur. Nowadays, this type of device is widely implemented in many Asian countries such as China, Thailand, Malaysia, and Turkey.

Countdown timers have been installed for both pedestrians and drivers. In Japan, the pedestrian countdown timer is rather common, especially at urban intersections. This type of device has the purpose of alerting crossing pedestrians to the remaining green time, mainly for safety reasons. Many researches can be found on the effects of the pedestrian countdown timer on the pedestrians; for example, Yoda and Mihoshi examined the impacts on pedestrians after the installation of the pedestrian countdown timers. The pedestrian countdown timer also has an effect on drivers. Huey and Ragland compared driver behaviors at two intersections in Berkley, CA: one with and one without the pedestrian countdown timer. Their findings indicated that drivers at the pedestrian countdown intersection were less likely to cross the intersection at the end of the drivers’ amber phase than those at the intersection without, as the timer made extra information available to drivers on the signal phase. Similar effects were found in the work of Schmitz in which the impacts of the pedestrian countdown timer on both pedestrians and drivers were observed at two signalized intersections in Lincoln, Nebraska: one with and another without the timer. The findings indicated that the pedestrian countdown timer increased pedestrian walking speed by 0.2 ft/sec, while vehicle speed at the stop line during the drivers’ amber phase decreased by 1.0 mi/hr.

The countdown timer for drivers is yet to be implemented in Japan. It should be noted that the signal cycle in the country is rather longer than is usual in Europe and in the United States. Without a countdown timer there is no information on the remaining phase time provided to drivers, resulting in difficulties for drivers to correctly estimate the timing of signal phase change. This uncertainty generates delays in drivers’ startups when the signal switches from red to green. In addition, long waits at red lights may cause stress or frustration to drivers, which might result in poor decisions.

Much research claims that the driver countdown timers improve traffic flow at intersections and reduce traffic accidents. Lum and Halim set up a Green Signal Countdown Device (GSCD) and conducted a before-and-after study on the effects of the device (including before and after the installation for 1.5, 4.5, and 7.5 months). They examined whether displaying the remaining green time can reduce the proportion of red light violations. Their findings demonstrated clearly a reduction in the proportion of red light violations after the installation of GSCD, especially when the traffic volume was relatively high. Zhang et al. also conducted a study on the effects of a countdown device on driver behavior during the seven days before and after the installation of the device in Beijing, China. They found that amber crossing and red light running decreased significantly after the installation of the countdown device. On the other hand, according to many studies, the countdown timer for drivers may not always lead to a desirable outcome. Long et al. indicated an unfavorable impact of the countdown timer on driver behavior. They investigated the effect of the timers at intersections in Changsha, China. The results showed that the countdown timers significantly influenced drivers’ decision whether to stop or to cross the intersection; they also influenced the distribution of vehicle entry times. There was also a strong correlation between the presence of the countdown timer and an increased proportion of red light violation at the intersection. The countdown timers may also lead to an increased proportion of vehicle entry into the intersection during the later portions of amber, or during inter-green, or sometimes during the beginning of red period. Similar findings were reported by Ibrahim et al. who compared the results between three intersections with the countdown timers and three other intersections without a countdown timer in Malaysia. They found that the rate of red light violation was greater at the intersections with a countdown timer than at those without a timer. Thus, further study is required in order to improve the operation of such devices and to investigate every aspect of their impact on driver behavior.

Considerable research has indicated a beneficial effect of the countdown timers on startup delay at intersections. The startup delay caused by the first vehicle in the queue at a signalized intersection delays the following vehicles and can lead to serious traffic congestion, especially during heavy traffic. With the countdown timer, drivers can estimate the proper timing for maneuvers at intersections, resulting in a better queue discharge. Some studies regarding the impacts of the countdown timer on driver’s startup maneuver can be found. For example, Limanond et al. compared the queue discharge characteristics with and without a countdown timer.
at an intersection in Bangkok and found that the countdown timer can reduce the startup delay by 1.00–1.92 seconds per cycle. Fujita et al.\textsuperscript{11,12} conducted surveys to compare driver behavior with and without countdown timers at two intersections in Kayseri, Turkey. Similarly, Yu et al.\textsuperscript{13} analyzed the startup behavior of drivers at countdown-signalized intersections in Changchun, China. The surveys in Turkey and China implied that the countdown timer can reduce the startup delay, but at the same time increases the proportion of red light violation at startup (hereafter called “premature start”), since drivers sometimes start to move the vehicle too early. However, the countdown timer was shown to be one of the best measures to reduce driving frustration. The questionnaire survey in Kayseri, Turkey conducted with 201 drivers who drove through the intersection when the countdown timer was first implemented, demonstrated that 80% of the drivers feel that the timer helped to relieve stress while waiting for the green phase at the intersection.

In those countries where the countdown timers are implemented, it is very common to find a continuous countdown timer in which the remaining time is shown in numbers of seconds until right before the signal changes. However, based on the above findings, displaying the signal this way may be a cause of the increased occurrence of premature starts. In this study, we thus conduct an experiment to investigate and compare the impacts of 10 different display patterns of the countdown timer and also without a timer, on driver behavior in order to find the optimal setting by which the benefit of the countdown timer in reducing startup delay is retained while occurrences of premature starts are reduced. We aim to test our hypothesis that stopping the countdown timer a little while before the exact timing of the signal phase change can reduce the occurrence of the red light violation on startup when the signal switches from red to green. In European Countries, there is another method to alert drivers of the coming green by showing both amber and red for a few seconds before green. However, this type of setting is not a common practice in Japan and our focus is on the impact of the countdown timer; thus this setting is not included in this experiment.

The details of the experiment are provided in the next section. The distributions of startup delay are presented. Several impacts on driver behaviors due to the different patterns of the countdown timer are also analyzed using regression and binary logistic regression techniques in order to examine the factors influencing both startup delay and the occurrence of premature start.

2. AN EXPERIMENT

An experiment to observe the driver startup behavior in response to the countdown timer was set up at the Nagoya Institute of Technology (NITech), Japan. The experiment was performed for four days: 30 November 2013, 15 December 2013, 11 January 2014, and 12 January 2014. To avoid interruption by other factors, the experiment was performed on either Saturday or Sunday and the area was closed to other vehicles and university students and staff.

As the countdown signal is yet to be implemented in Japan, we thus installed our own countdown timer developed at NITech, at an intersection within the university campus. The device is a Japanese standard size of 300 mm diameter LED countdown device, which can display characters in the middle of the light as shown in Fig. 1 and is clearly visible from a distance. The device can be set to display both with and without the countdown timer and other preset characters during green and red phases.

The driving course and the location of the countdown timer and video cameras are shown in Fig. 2. Two video cameras were used: Camera 1 was set at an angle for clear visibility of the head of the vehicle and the stop line in order to record the startup behavior of drivers and the position of vehicles. Camera 2 points to the signal device and the entire vehicle for recording the signal cycle. Sixteen drivers were requested to participate in this experiment.

![Fig. 1 Our own developed countdown device.](image1)

![Fig. 2 Driving course.](image2)
Table 1 shows the attributes of the drivers by sex, age group, driving experience, and driving frequency. The drivers were allowed to drive the course in one direction only, as shown by the blue line in Fig. 2(a). Two rental cars were used in the experiment: a 1,198cc Nissan Note with Automatic transmission and idling stop system and a 1,329cc Toyota Vitz with Automatic transmission and without an idling stop system, in order to explore the effect of the idling stop system on the startup behavior as well.

Table 2 depicts the 11 display patterns of the countdown timer for signal change from red to green used in the experiment. NoCount means the normal signal display without the countdown timer. 5sRed means decreasing the number every second until 5 seconds and then switching to display a solid red until the upcoming green phase. 5sNum is similar to 5sRed; however, instead of switching to a solid red, the number 5 in the timer remained unchanged until the upcoming green phase. 5sSeq means to count down in a sequence of 5-second blocks until the upcoming green phase. 3sRed, 3sNum, and 3sSeq are similar to 5sRed, 5sNum, and 5sSeq respectively, but the timer is stopped at 3 seconds or the countdown steps are performed in units of 3 seconds. Likewise, 2sRed and 2sNum stop 2 seconds before the change, and 2sSeq counts down in units of 2 seconds. The normal countdown method was also included in the experiment as 1sCount in which the timer counted down by single seconds continuously until the green phase.

The details of the experiment are shown in Table 3. The experiment was divided as shown in the table for convenience of the participants. The countdown patterns were shown to drivers in the sequence as depicted in the table. For each countdown pattern, two drivers were requested to drive at the same time for 15–20 minutes in the driving course, which can be completed in approximately 3 minutes. Thus, each driver drove for approximately 5–6 rounds per countdown pattern. Then, drivers were allowed to take a rest and fill a questionnaire while the other two drivers were driving the course, and later swapped to drive the next rounds for the next pattern. This process was repeated until each driver experienced all the countdown patterns in each session.

| Attributes       | Number of drivers |
|------------------|-------------------|
| Sex              | Male, Female      |
| Age              | 20–29, 30–39, 50–59 |
| Driving Experience | ≤ 5 years, ≥ 18 years |
| Driving Frequency | ≤ 3 times a month, 1–4 times a week, ≥ 5 times a week |

Table 2 Countdown patterns.

| Countdown Pattern | Remaining Red Time (sec) | Green Time |
|-------------------|--------------------------|------------|
| NoCount           |                          |            |
| 5sRed             | 15 14 13 12 11 10 9 8 7 6 5 |            |
| 5sNum             | 15 15 15 15 15 15 10 10 10 10 5 |            |
| 5sSeq             | 15 15 15 15 15 15 15 15 15 15 5 |            |
| 3sRed             | 15 15 15 15 15 15 15 15 15 15 5 |            |
| 3sNum             | 15 15 15 15 15 15 15 15 15 15 5 |            |
| 3sSeq             | 15 15 15 15 15 15 15 15 15 15 5 |            |
| 2sRed             | 15 15 15 15 15 15 15 15 15 15 5 |            |
| 2sNum             | 15 15 15 15 15 15 15 15 15 15 5 |            |
| 2sSeq             | 16 16 16 16 16 16 16 16 16 16 6 |            |
| 1sCount           | 15 15 15 15 15 15 15 15 15 15 5 |            |
Table 3  Experiment details.

| Date & Time  | Countdown Patterns                  | Red Time |
|-------------|------------------------------------|----------|
| 30-Nov 2013 Morning | NoCount, 5sRed, 3sRed, 1sCount 5sNum, 3sNum, 2sNum | 15s      |
| 30-Nov 2013 Afternoon | NoCount, 5sRed, 3sRed, 1sCount 5sNum, 3sNum, 2sNum | 40s      |
| 15-Dec 2013 Morning | NoCount, 5sRed, 3sRed, 1sCount 5sNum, 3sNum, 2sNum | 60s      |
| 15-Dec 2013 Afternoon | NoCount, 5sRed, 3sRed, 1sCount 5sNum, 3sNum, 2sNum | 60s      |
| 11-Jan 2014 Morning | 2sRed, 5sSeq, 3sSeq, 2sSeq | 60s      |
| 11-Jan 2014 Afternoon | 2sRed, 5sSeq, 3sSeq, 2sSeq | 60s      |
| 12-Jan 2014 Morning | 2sRed, 5sSeq, 3sSeq, 2sSeq | 60s      |
| 12-Jan 2014 Afternoon | 2sRed, 5sSeq, 3sSeq, 2sSeq | 60s      |

Each driver was assigned to drive the same car for the entire experiment. The signal device was installed as similarly as possible to those found on public roads. However, the height of the traffic light in the experiment was lower than that in the actual practice due to limitation of the experiment setup. The drivers were asked to drive naturally, as they do in daily life. However, the drivers were not allowed to change lane or overtake for safety reasons, but other than these restrictions they could drive freely. We have not yet included an in-a-hurry driving condition in this experimental setup.

Once each countdown pattern was finished, the drivers were asked to fill in questionnaires regarding their satisfaction with the system. The questions addressed issues including: 1) comfortable driving, 2) safety, and 3) satisfaction level. Finally, they were asked to choose their preferred setting among all the countdown patterns.

3. ANALYSIS RESULTS

In this section, the impacts of different countdown patterns are analyzed with a focus on the startup delay and any anticipated startup of the first vehicle in the waiting queue.

(1) Startup delay

Startup delay is normally defined as the time difference between instances when the signal changes from red to green and when front of the vehicle passes the stop line. In practice, however, we often found that although the head of the vehicle had not yet passed the stop line, the driver had already started to move the vehicle by releasing the brake pedal. This action is dangerous especially when the stop line is very close to the pedestrian crossing. In this study, two types of startup delay were analyzed:

**Startup response time**: The time difference between instances when the signal changes from red to green and when the driver releases the brake pedal.

**Startup delay–Stop line**: The time difference between instances when the signal changes from red to green and when the head of the vehicle passes the stop line.

(b) Statistics tests results ( Note:* test at 95 percent level of confidence)

![Fig. 3 Mean startup delay between with and without timer.](image-url)
Figure 3 compares the means of the two types of startup delay between cases with and without the countdown timer. The results show that the countdown timer can reduce the average startup delay by 0.56 second for startup response and by 0.47 second for reaching the stop line. In this experiment, it took an average of approximately a second after releasing the brake pedal until the head of the vehicle reached the stop line.

Table 4 shows the means and variances of the startup delay by countdown pattern and by each type of startup delay. 5sCount includes all countdown patterns stopping 5 seconds before the green phase, 5sRed, 5sNum, and 5sSeq. Similarly, 3sCount includes 3sRed, 3sNum, and 3sSeq. 2sCount includes 2sRed, 2sNum, and 2sSeq. The mean startup delay of NoCount is longer than those of 5sCount, 3sCount, and 1sCount. Furthermore, stopping the countdown timer earlier causes a longer startup delay.

Table 5 shows p-values resulting from t-tests of different means of startup response time for all countdown patterns. Showing the solid red light (e.g., 3sRed) and keeping the number unchanged (e.g., 3sNum) once the timer stops give quite similar mean values. 2sNum has a similar impact on the response time as that of 1sCount.

Figure 4 depicts the distributions of startup delay by countdown pattern and by measure of startup delay. For each pattern, 95% of the data are lined up as shown.

| Patterns | N | Response | Mean | Var. | Stop line | Mean | Var. |
|----------|---|---------|------|------|-----------|------|------|
| NoCount  | 62| 1.00    | 0.11 |      | 2.00      | 0.40 |      |
| 5sRed    | 69| 0.61    | 0.58 | 1.72 | 0.35      |      |      |
| 5sNum    | 111| 0.61 | 0.52 | 1.62 | 0.44      |      |      |
| 5sSeq    | 102| 0.66 | 0.53 | 1.80 | 0.43      |      |      |
| 3sRed    | 72| 0.52 | 0.32 | 1.61 | 0.35      |      |      |
| 3sNum    | 108| 0.52 | 0.23 | 1.54 | 0.43      |      |      |
| 3sSeq    | 104| 0.38 | 0.49 | 1.59 | 0.35      |      |      |
| 2sRed    | 99| 0.28 | 0.52 | 1.40 | 0.44      |      |      |
| 2sNum    | 109| 0.25 | 0.36 | 1.30 | 0.58      |      |      |
| 2sSeq    | 107| 0.41 | 0.57 | 1.53 | 0.57      |      |      |
| 1sCount  | 76| 0.21 | 0.39 | 1.17 | 0.45      |      |      |

Table 5 P-value of different means of startup response time.

| Patterns | NoCount | 5sRed | 5sNum | 5sSeq | 3sRed | 3sNum | 3sSeq | 2sRed | 2sNum | 2sSeq | 1sCount |
|----------|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|
| NoCount  | .       | .     | .     | .     | .     | .     | .     | .     | .     | .     | .       |
| 5sRed    | ***     | .     | .     | .     | .     | .     | .     | .     | .     | .     | .       |
| 5sNum    | ***     | 0.9682| .     | .     | .     | .     | .     | .     | .     | .     | .       |
| 5sSeq    | ***     | 0.5793| 0.5583| .     | .     | .     | .     | .     | .     | .     | .       |
| 3sRed    | ***     | 0.4419| 0.3608| 0.1607| .     | .     | .     | .     | .     | .     | .       |
| 3sNum    | ***     | 0.2769| .     | 0.9408| .     | .     | .     | .     | .     | .     | .       |
| 3sSeq    | ***     | ***   | ***   | ***   | 0.1530| 0.1305| .     | .     | .     | .     | .       |
| 2sRed    | ***     | ***   | ***   | ***   | ***   | ***   | 0.2791| .     | .     | .     | .       |
| 2sNum    | ***     | ***   | ***   | ***   | ***   | ***   | 0.1566| 0.7609| .     | .     | .       |
| 2sSeq    | ***     | *     | **    | ***   | 0.2658| 0.2458| 0.7192| 0.1486| *     | .     | .       |
| 1sCount  | ***     | ***   | ***   | ***   | ***   | ***   | ***   | 0.4687| 0.6478| **    | .       |

Note: *, **, and *** indicate the significance at 90%, 95%, and 99% levels of confidence, respectively.
within the highest top and lowest bottom lines, while the box shows the variance and the thick line in the middle of the box indicates the mean value. Data in minus value for the startup response time indicate that the drivers started to release the brake pedal before the green phase. With regard to the startup delay–Stop line, a minus value corresponds to a premature start as the head of the vehicle has reached the stop line before the start of the green phase.

From the data, the trend shows that the countdown timer induces an increased occurrence of premature starts. Especially, the 5sCount (which consist of 5sRed, 5sNum, and 5sSeq) cause some drivers to react too soon, the extreme case of reacting at more than 1.5 seconds before green occurred at most in the 5sCount (accounted for 2.85% on average). The extreme cases of the 3sCount, 2sCount, and 1sCount are 0.32%, 1.63%, and 1.32%, respectively.

Although most of the time the head of the vehicle did not reach the stop line before the green phase, the drivers had a tendency to release the brake pedal early. This is because the 5-second lag until the green phase is too long for the drivers to predict the correct timing of the green, resulting in too-early or sometimes too-late responses. The values of 3sRed and 3sNum are more closely bunched within a narrower 95% range compared to the other countdown patterns. 3sNum in particular has a narrow range with only one outlier in the early response category. The detailed analysis of premature start by countdown patterns will be discussed in the next section.

In the presence of a countdown timer, the car with the idling stop system is significantly affected, which is shown in Fig. 5. The idling stop system stops the engine every time the driver puts on the brake pedal for a while (this occurs most often when waiting at red lights) and restarts the engine again when the driver releases the pedal. Normally, this system requires a longer startup time.

However, our results show that drivers with the idle stop system, when with the countdown timer, responded quicker by 0.72 (1.10-0.38) second than when without the timer. These drivers appear to have compensated for their longer startup time by preparing to be ready to start at the proper time, resulting in a significant reduction in their startup delay.

(2) Startup delay model

We used a regression model to analyze the factors influencing startup delay. The delay is defined as when the head of a vehicle passes the stop line (see the definition of Startup delay–Stop line). For startup response time, the available factors in this experiment were not enough to be explained in a regression model and thus the model is not presented here but will be analyzed as a logistic regression in the next section. The parameters put into the model include the distance from the head of vehicle to the stop line, a dummy variable for each of the countdown patterns, a dummy variable for the idling stop system, a dummy variable for number of rounds the driver drove from the beginning of the experiment (Entire
Driving Times), a dummy variable for number of rounds the driver drove from the beginning of the current countdown pattern, and dummy variables for the attributes of drivers (including sex, age, driving experience, and driving frequency). The countdown patterns that give a very similar mean value for startup response time (based on the results in Table 5) are grouped together.

Table 6 demonstrates the best fit model for startup delay measured by when the head of the vehicle reached the stop line. The analysis results show that the countdown timer can reduce startup delay as drivers can easily estimate the proper timing to start their maneuver. When counting down until 1 second before the phase change, the reduction in startup delay is more than that of the other patterns where the timer is stopped earlier. Regarding the methods for counting down, counting down and then switching to show a solid red light or keeping the number unchanged have a similar impact. However, decreasing the number in fixed multi-second increments affects drivers’ responses differently. Stopping the timer later more significantly reduces the startup delay. The number of times the driver drove from the beginning of each pattern was not significant in this case because probably it was too small to adapt to the system. Similarly, the number of rounds the driver drove from the beginning of the experiment was not relevant to the model.

Table 6: Startup delay model for cases when the head of the vehicle passed the stop line.

| Parameters                              | Estimation | t-value |
|-----------------------------------------|------------|---------|
| Intercept                               | 1.4853     | 30.21***|
| Distance to stop line (cm)              | 0.0048     | 21.31***|
| 1sCount (dummy)                         | -0.5832    | -8.28***|
| 2sRed and 2sNum (dummy)                 | -0.4377    | -8.23***|
| 3sRed and 3sNum (dummy)                 | -0.2593    | -4.72***|
| 5sRed and 5sNum (dummy)                 | -0.1268    | -2.31** |
| 3sSeq and 2sSeq (dummy)                 | -0.2543    | -4.80***|
| Idling stop w/Count (dummy)             | -0.2034    | -6.08***|
| Frequency ≥ 5 times a week (dummy)      | -0.2551    | -6.86***|

| Parameters                              | Estimation | t-value |
|-----------------------------------------|------------|---------|
| Intercept                               | 1.4853     | 30.21***|
| Distance to stop line (cm)              | 0.0048     | 21.31***|
| 1sCount (dummy)                         | -0.5832    | -8.28***|
| 2sRed and 2sNum (dummy)                 | -0.4377    | -8.23***|
| 3sRed and 3sNum (dummy)                 | -0.2593    | -4.72***|
| 5sRed and 5sNum (dummy)                 | -0.1268    | -2.31** |
| 3sSeq and 2sSeq (dummy)                 | -0.2543    | -4.80***|
| Idling stop w/Count (dummy)             | -0.2034    | -6.08***|
| Frequency ≥ 5 times a week (dummy)      | -0.2551    | -6.86***|
| R²                                      | 0.41       | -       |
| N                                       | 1016       | -       |

Note: ** 95% level of confidence and *** 99% level of confidence.

The idling stop system in the presence of countdown timer also has a positive impact on the reduction of the startup delay. The greater the distance of the head of the vehicle from the stop line, the longer the startup delay. Drivers with driving frequency of more than or equal to five times a week tend to have a shorter startup delay.

(3) Anticipated startup

This section is devoted to the analysis of the relationships of the different countdown patterns to the occurrence of anticipated response at startup. Just as for the startup delay criteria of the response action and reaching the stop line in the previous section, two types of anticipated startup are defined in this study as follows:

**Early Response:** When a driver waiting during a red light starts to release the brake pedal before the signal changes from red to green.

**Premature Start:** When a driver waiting during a red light has moved the head of the vehicle up to the stop line before the signal changes from red to green.

Figure 6(a) depicts the proportion of the occurrences of anticipated startup by countdown pattern and type.

(a) The proportion of the occurrences of anticipated startup

(b) The proportion of the response before 0.5 second to green.

(Note: ** significant at 95% level of confidence)

Fig. 6 The proportion of occurrence of anticipated startup by countdown patterns.
Without the timer, there is no occurrence of premature start in this experiment. This can be explained by the absence of stimuli predicting the change of phase. There is no pedestrian signal or traffic signal for another direction. In contrast, counting down until 1 second has the highest proportion of anticipated startups. The proportion of anticipated startups increases when the timer is stopped for a shorter period.

The startup delay of the 5-second countdown patterns is longer than those of the other countdown patterns, as shown in Fig. 4. However, the greatest anticipated releases of the brake pedal, more than 3 seconds before green, also occurred, especially for the pattern of 5sRed. Perhaps, the five-second duration was too long and the drivers may have sometimes miscalculated the correct timing. When measuring instances when the head of the vehicle reached the stop line, the incidence of actual premature starts was rare: 0 case for NoCount and 3sRed; one case for 5sRed, 5sNum, 3sNum, and 3sSeq; two cases for 5sSeq, 2sRed, and 2sNum; four cases for 2sSeq; and five cases for 1sCount. This is because frequently when the timer which had continuously counted suddenly stopped, many drivers responded by at once releasing the brake; later, they noticed their mistakes and put on the brake pedal again. The percentages of such occurrences by countdown patterns are shown in Fig. 7. The drivers reacting to the 5sRed had the highest pattern, followed by the 3sRed pattern because of the sudden disappearance of the countdown number. A five-second or three-second duration is easily long enough for a vehicle to reach the pedestrian crossing.

**Table 7** Binary logistic regression model for the response before the green phase.

| Parameters                          | Model 1          | Model 2          | Model 3          |
|-------------------------------------|------------------|------------------|------------------|
|                                     | Estimation       | t-value          | Estimation       | t-value          | Estimation       | t-value          |
| Intercept                           | -3.1610          | -7.96***         | -3.6240          | -10.87***        | -1.4240          | -3.15***         |
| 1sCount (dummy)                     | 1.6140           | 4.68***          | 1.9360           | 6.32***          | 1.9190           | 6.01***          |
| 2sRed and 2sNum (dummy)             | 0.8469           | 4.03***          | 0.9768           | 4.90***          | 1.0070           | 4.90***          |
| 5sRed and 5sNum (dummy)             | -0.4517          | -1.30            |                  |                 |                  |                 |
| NoCount (dummy)                     | -1.8930          | -1.77*           |                  |                 |                  |                 |
| Idling stop w/Count (dummy)         | 0.6816           | 3.62***          | 0.7354           | 3.94***          | 0.8907           | 4.57***          |
| Driving experience (years)          | -0.0783          | -5.80***         | -0.0787          | -5.78***         | -0.0865          | -6.42***         |
| Driving ≥ 5 times a week (dummy)    | 2.1930           | 7.66***          | 2.1520           | 7.56***          | 2.3090           | 7.58***          |
| Driving 1-4 times a week (dummy)    | 1.0400           | 3.96***          | 1.0040           | 3.83***          | 0.8173           | 2.97***          |
| Entire Driving Times (dummy)        | 0.0126           | 1.85           | 0.0213           | 3.99***          | 0.0188           | 3.45***          |
| Startup speed (m/s)                 |                  |                  |                  |                  | -1.9640          | -6.64***         |
| N                                  | 1019             | 1019             | 1019             |
| $\rho^2$                           | 0.41             | 0.41             | 0.44             |
| Hit Ratio                          | 82.1%            | 81.8%            | 82.3%            |

Note: *, **, and *** indicate the significance at 90%, 95%, and 99% level of confidence, respectively.
after releasing the brake; hence, these patterns may cause dangerous situations.

For 3sRed and 3sNum, most of the startup response times were between -1 and 1.75 seconds and there were few extreme cases of an anticipated response. The 2-second countdown patterns gave rather similar outcomes to that of the 1-second countdown pattern.

It appears that releasing the brakes at 0.5 second before green causes few premature starts (from our observations, unless the vehicle was stopped a few centimeters from, or over, the stop line, a 0.5-second duration was too short for the vehicle to start moving and reach the stop line before green). Figure 6(b) shows the proportion of the responses before 0.5 second to green for each countdown pattern. The Pearson chi-square test indicates that the countdown pattern significantly influences the proportion of the occurrence. The 3sNum shows the lowest proportion of early response among all the countdown patterns. The sequence of continuously counting down by a second, stopping the timer, and suddenly switching to red causes a reaction from some drivers due to the obvious lack of continuity. Instead of showing a red light, keeping the number unchanged can reduce this reaction since the change is less abrupt.

(4) Anticipated startup model

Since occurrences of actual red light violations are rare for each of the patterns, we thus focus here on the tendency to anticipate brake release. More often, drivers respond before the start of green time (see the definition of Early Response). Although the head of the vehicle may not have reached the stop line, this maneuver is also dangerous, especially to the crossing pedestrians.

Two binary logistic regression models showing the tendency of anticipated startup to occur, focusing on when the driver started to respond (Early Response), were developed in order to explore the influencing factors. A driver who started to release the brake pedal before the green light goes on exactly was set to 1, and otherwise to 0. The calibration results are depicted in Table 7. Model 1, Model 2, and Model 3 were developed to predict early response behavior. The parameters put into the models included the distance from the head of vehicle to the stop line, a dummy variable for each of the countdown patterns, a dummy variable for the idling stop system, a dummy variable for number of rounds the driver drove from the beginning of the experiment (Entire Driving Times), a dummy variable for number of rounds the driver drove from the beginning of the current countdown pattern, and a dummy variable for each of the attributes of drivers (including sex, age, driving experience, and driving frequency). For the dummy variables for the countdown patterns, countdown patterns that give a very similar mean value for startup response time based on the results in Table 5 are grouped together.

In Model 1, 1sCount tends to induce drivers to respond before the green phase more than the other countdown patterns that stop the timer earlier. Counting down and then switching to show a solid red or keeping the number unchanged give a similar result and are thus grouped together. The parameter for 2sRed and 2sNum has positive sign, meaning that these countdown patterns induce the occurrence of early response. On the other hand, the negative value of the parameter for 5sRed and 5sNum means that

| Parameters                      | Model 4    |       | Model 5    |       |
|---------------------------------|------------|-------|------------|-------|
| Intercept                       | -4.0910    | -8.59 | -3.7700    | -8.73 |
| 3sNum (dummy)                   | -1.7530    | -2.34 | -1.8160    | -2.48 |
| Idling stop w/Count (dummy)     | 1.0340     | 3.80  | 1.0820     | 4.00  |
| Driving experience (years)      | -0.1026    | -3.15 | -0.1019    | -3.13 |
| Driving >= 5 times a week (dummy) | 2.4120    | 5.55  | 2.4570     | 5.67  |
| Driving 1-4 times a week (dummy) | 1.0100    | 2.36  | 1.0320     | 2.41  |
| Entire driving times (dummy)    | 0.0108     | 1.71  | -          | -     |

N 1019 1019

\( \rho^2 \) 0.66 0.65

Hit Ratio 91.8% 91.8%

Note: ** 95% level of confidence and *** 99% level of confidence.
the 5-second countdown patterns lessened the problem of drivers responding early which is similar to the NoCount pattern.

In Model 2, the parameters are calibrated again in order to remove the parameter for 5sRed and 5sNum, which is below 90% level of confidence and the parameter for NoCount as it is highly correlated to the variable for the numbers of rounds drivers drove from the beginning of the experiment.

A parameter for startup speed is added into Model 3 in order to clarify the behavior of the drivers who have the tendency to respond early. The startup speed was calculated considering the distance from the head of vehicle to the stop line and the time required from releasing the brake pedal until the head of vehicle reached the stop line. The parameter of startup speed has a minus sign and can be explained by the video record, which shows that drivers tended to respond early, moved the vehicle slowly, little by little, until the exact timing of the signal phase change and then started to increase the speed. The other drivers tended to wait until the proper timing and started the vehicle at a faster speed.

In all models, drivers with the idling stop system tended to respond too early in the presence of countdown timer. This might be because the drivers knew the disadvantage of the system, which normally required a few seconds to start the engine after releasing the brake pedal. Hence, drivers were prepared to startup quicker to avoid such delays, which often resulted in an early response. Drivers with higher driving frequencies tended to respond earlier. However, drivers with more driving experience tended not to respond early. The distance to stop line was not significant in this model because this model considered the timing when drivers started to respond to the signal. Waiting time was also considered in the analysis; however, this variable was not significant since the waiting time in this experiment was rather short, with the maximum waiting time being 60 seconds. The numbers of rounds drivers drove from the beginning of each pattern was not relevant to all models.

Next, assuming that the drivers who started to release the brake pedal before 0.5 second to green light are considered as having a tendency to respond early (from the observation stated previously), a similar binary logistic regression model was developed and is depicted in Table 8. The vehicle with the startup delay below -0.5 second is set to 1 and otherwise to 0. Based on the calibrated results in Model 4, while the variables for the other countdown patterns are not significant, only the parameter for 3sNum is found significant and has a minus sign. This can be interpreted as the 3sNum pattern reducing the tendency of drivers to respond early as it took a few seconds for the drivers to notice that the timer had stopped. The other variables for the attributes of the drivers and the vehicles can be interpreted similarly as stated above. In Model 5, the numbers of rounds drivers drove from the beginning of the experiment was removed as it was below 90% level of confidence.

Comparing the results, Table 6 suggests that the countdown timer is able to reduce startup delay; however, the results in Table 7 show that it may also lead to the possibility of early responses. It is perhaps better not to show the countdown timer at all in order to control the problem of red light violations. However, the countdown signal is preferred for many reasons, such as reducing startup delay and driver stress and safety reasons. Based on the values shown in Table 8, we therefore suggest to stop the timer a little earlier (approximately 3 seconds) and keep the number unchanged until the green phase. This technique would leave the exact timing of the signal change unclear to drivers, but drivers would still be alerted by the countdown timer to the imminent phase change.

(5) Driver satisfaction

At the end of the experiment, drivers were asked to select their most preferred countdown pattern. Based on the questionnaire results, Fig. 8 shows the share of the most favorite pattern in this experiment. Forty-one percent of drivers selected 1sCount as their most favorite pattern, as it is the easiest pattern for the drivers to predict the correct timing. The second and the third favorites are 3sRed (22%) and 3sNum (13%), respectively.

The 3-second countdown patterns seemed to be favored by some drivers because they felt it was natural to start to move the vehicle within that duration. To stop counting down and to switch to a solid red light was preferable to displaying an unchanged number because some drivers felt an inconsistency

![Fig. 8 The most preferred countdown pattern.](image)
when the countdown stopped, but the number did not change. Obviously, having a countdown timer working continuously to the moment the signal changes can ease driving. Moreover, displaying the waiting time at a red light can lessen driver stress as the duration of waiting is known and drivers can be prepared for the timing of the upcoming green phase.

4. CONCLUSION

We have presented experimental results focused on drivers’ startup behavior influenced by a countdown timer when the signal changes from red to green. The experiment attempted to understand the impacts of the 11 display patterns of the countdown timer. These patterns include: without the timer; with the timer counting down every second; with the timer, but stopping the timer at different times (2, 3, and 5 seconds before the exact onset of the green phase); and with the timer, but counting down in increments of 2, 3, or 5 seconds. The findings can be summarized as follows:

- When the head of vehicle passed the stop line, both the presence of the countdown timer (for all display patterns) and drivers who drove more frequently tended to shorten the startup delay; a greater distance of the vehicle from the stop line caused a longer startup delay. Also, the presence of the countdown timer gave a significant reduction (65%) in the startup delay for drivers with the idling stop system, as compared to the absence of a timer.

- When stopping the countdown timer earlier, switching to display either a solid red or keeping the number unchanged (5sRed and 5sNum, 3sRed and 3sNum, and 2sRed and 2sNum) led to similar average startup delays.

- The startup delay increased as the duration of stopping the timer before the phase change increased. The countdown timer that displayed the number of seconds remaining until a second before the green light shortened the startup delay more than other countdown patterns that stopped the timer earlier. Conversely, the proportion of drivers who responded before the green light increased if displaying the timer until a second before the phase change.

- When the timer was stopped earlier, the startup delay was longer, while the proportion of responses before the green light was reduced. However, stopping the timer at 5 seconds earlier than the onset of the green phase caused a few extreme cases of early responses. It appeared to be because the 5-second duration was too long for the drivers to predict the correct timing.

- Based on the binary logistic regression model of the response before 0.5 second to green light, stopping the countdown timer for 3 seconds and then keeping the number fixed until the signal changed (3sNum) is perhaps the best way (compared to other display patterns in this experiment) to reduce the tendency of drivers to perform premature starts. This technique causes drivers to be less aware of the stopped timer and leaves the exact timing of the signal change unclear; however, the drivers are still being alerted by the countdown timer of the approaching phase change.

- Based on the questionnaire results of drivers’ opinions, the drivers feel relief while waiting at a red light with a countdown timer. They clearly prefer the normal timer that displays the time remaining until one second before green, because it is the easiest pattern with which to predict the correct timing. The 3-second countdown patterns (3sRed and 3Num) are the next most favored since the drivers find the 3-second duration to be the appropriate time for the startup maneuver.

However, this experiment was performed mainly with young male drivers and the countdown patterns might have different effects for more experienced drivers and women. Also, due to limitations of the experiment setup, the height of the signal light was lower than that in the actual practice, which might have caused better visibility of the signal light. The experiment condition may have influenced the results. In addition, in the experiment setup this time, the countdown patterns were presented to drivers in a sequence, although the dummy variable of the entire driving times was included to reduce the order effect in the models. However, presenting the countdown patterns randomly to drivers is suggested as a better treatment of the order effect.

A longitudinal study should be considered too, for the long-term impact of the countdown pattern on drivers, after they have adapted to the system. In addition, a more in-depth analysis of the relationship between each of the countdown patterns and the driver behavior should be undertaken. In particular, improving the validity of the results by increasing the number of participants, capturing a greater variety of driver attributes, and using a greater number of vehicles is very important. In addition, there are many other impacts of the countdown timer on drivers other than those presented here, such as the impact on queue discharge characteristics and the impact of a countdown timer on drivers during
switching from green to amber. Also, driver behavior differs markedly between countries and so these research results may not always apply to other countries. These issues remain for further investigation.

These findings should help researchers and policy makers as they can guide the implementation or the modification of countdown-signalized intersections in order to improve the safety of drivers and pedestrians while maintaining driver satisfaction. Obviously, the proposed method of displaying the countdown timer cannot eliminate red light violations. Other countermeasures to ensure safety, such as having a sufficient gap between the pedestrian crossing and the stop line, should be considered simultaneously.

REFERENCES
1) Limanond, T, Chookerd, S. and Roubtonglang, N.: Effects of countdown timers on queue discharge characteristics of through movement at a signalized intersection, Transportation Research Part C, Vol. 17, pp. 662-671, 2009.
2) Koll, H., Bader, M. and Axhausen, K. W.: Driver behavior during flashing green before amber: A comparative study, Accident Analysis & Prevention, Vol. 36, pp. 273-280, 2004.
3) Murata, K., Asano, M., Tanaka, S. and Kuwahara, M.: Analysis of pedestrian crossing behavior with remaining green time provision, IATSS Review, Vol. 31, No. 4, pp. 76-83, 2007.
4) Yoda, T. and Mihoshi, A.: A study on the effects of countdown signal on pedestrians, Proc. JSCE-Kansai, 2001.
5) Huey, S. B. and Ragland, D.: Changes in driver behavior resulting from pedestrian countdown signal, Proc. 86th Annual Meeting TRB, 2007.
6) Schmitz, J. N.: The Effects of Pedestrian Countdown Timers on Safety and Efficiency of Operations at Signalized Intersections, Civil Engineering Theses, Dissertations and Student Research, University of Nebraska-Lincoln, http://digitalcommons.unl.edu/civilengdiss/28, 2011.
7) Lum, K. M. and Halim, H.: A before-and-after study on green signal countdown device installation, Transportation Research Part F, Vol., 9, pp. 29-41, 2006.
8) Zhang, J., He, Y. and Sun, X.: The effects of countdown signal on driver behavior at intersection in a city, Proc. ICCTP 2010, pp. 262-268, 2010.
9) Long, K., Han, L. D. and Yang, Q.: Effects of countdown timers on driver behavior after the yellow onset at Chinese intersections, Traffic Injury Prevention Journal, Vol., 12, No. 5, pp. 538-544, 2011.
10) Ibrahim, M. R., Karim, M. R. and Kidwai, F. A.: The effect of digital count-down display on signalized junction performance, American J. Applied Sciences, Vol., 5, No. 5, pp. 479-482, 2008.
11) Fujita, M., Suzuki, K. and Yilmaz, C.: Behavior and consciousness analyses of effect of traffic signals including countdown device for vehicles, J. of Easts., Vol. 7, pp. 2289-2304, 2007.
12) Fujita, M., Suzuki, K. and Yilmaz, C.: Analysis of the effects of countdown signals to drivers in Kayseri Province, Turkey, Proc. 7th ITS symposium, Vol. 7, pp. 169-174, 2008.
13) Yu, K., Fujita, M. and Suzuki, K.: Behavior analysis of vehicle starts under countdown-type traffic signal through survey in China, World Academy of Science, Engineering and Technology, Vol. 58, pp. 250-255, 2011.

(Received March 4, 2015)