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# Impact of countdown signals on traffic safety and efficiency: a review and proposal

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## Abstract

Countdown signals for motorized vehicles, which are intended to ensure safety on the road and regulate motor vehicle speed limits at road intersections, are still considered a relatively novel concept. These signals have been adopted by only a few countries, and the number of cities that use them is limited. This review aims to summarize the effects of countdown signals on traffic safety and efficiency and to determine the consistency and differences of existing research propositions on the matter. Based on the review, considerable research presents evidently different conclusions in the areas of driver red-light running and traffic safety. Particularly, some studies propose that countdown signals reinforce traffic safety, whereas others consider that such signals adversely affect traffic safety. Meanwhile, related literature provides varying conclusions on the aspect of traffic efficiency for vehicle headway. At present, the number of studies conducted regarding the driving behaviors of motorists toward countdown-signalized intersections is insufficient. Accordingly, such inadequate diversity in research causes difficulty in completely assessing the benefits and disadvantages of countdown signals. In this paper, an important future research direction on microcosmic driving psychological and physiological data combined with macro-driving behavior is proposed.

**Keywords:** Countdown signals; Driving behavior; Red-light running; Traffic safety; Traffic efficiency

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## Introduction

Road intersections generally consist of unsignaled and signaled intersections, in which the latter are regulated by traffic control signals. Traditional signals emit LED lights in the form of uniform balls. However, the types and structures of signal lights have changed, in which some flash signal lights in the forms of arrow, pedestrian, and bicycle. Countdown signal lights have also emerged. These signals refer to the new type of traffic lights assembled by ordinary signal lights, and the countdown device or timer that indicates the normal signal phase colors can simultaneously display the remaining time of the signal phase, thereby enabling drivers and pedestrians to choose a traffic behavior, that is, to stop or cross the intersection. Road intersections equipped with countdown signal lights are called countdown-signalized intersections.

Countdown signals can be classified into motorized vehicle, non-motorized vehicle, and pedestrian countdown signals. Motorized vehicle countdown signals include two types, namely, green and red. Figure 1 shows an example of two types of motorized vehicle countdown signal located in Qingdao City, Shandong Province, China.

Motorized vehicle countdown signals have a significant influence on road traffic control. In particular, if countdown signals adversely affect the driving behaviors of motorists, traffic safety is compromised. Consequently, this study focuses on motorized vehicle countdown signals. In this paper, if the type of countdown signal is not specified, motorized vehicle countdown signals are referred to.

According to data provided by the National Bureau of Statistics of China, there were 273,098 traffic accidents in China in 2021, of which 233,729 were motor vehicle accidents, accounting for 85.58% of the total traffic accidents. Research has shown that traffic accidents occurring at intersections account for approximately 20% of the total number of motor vehicle traffic accidents[1,2]. As an important controller at intersections, signal lights are crucial for traffic safety and should receive people's attention.

Countdown signals display the remaining time of passage, or the time that drivers and pedestrians must wait before crossing the road. These traffic signals motivate road users to be cautious; thus, the use of such signals has been widely accepted. Nevertheless, doubts exist on the safety of these signals. Although they are intended to improve traffic efficiency, countdown signals may affect the traffic psychology and behavior of motorists and pedestrians as well as evoke latent danger[3]. A countdown signal typically flashes a green light that allows traffic to proceed in the indicated direction and a red light that prohibits any traffic from proceeding. The countdown signal displays the remaining time of the go signal phase, which may induce some drivers to accelerate to pass through the intersection before the light changes; also, the countdown signal displays the remaining stop signal phase, which may induce some drivers to start their vehicles immediately so that they can get ahead of other vehicles when the light changes. Both cases can result in traffic conflicts, which may lead to traffic accidents.


**Fig. 1** Two types of motorized vehicle countdown signals.

Especially for new drivers, the change from a green to a red signal may cause psychological pressure on them. Is it to continue to drive the vehicle through the intersection? Or wait for the next green signal? The new driver may have the hesitant situation. This is because drivers without driving experience tend to have immature driving psychology and driving behaviors, don't know how to appropriately deal with the appearance of a sudden traffic incident, and even feel nervous when they meet a countdown signal conversion[4]. This is likely to increase the unsafe situation at countdown signalized intersections.

To date, countdown signals are still a relatively new concept. This paper summarizes the studies on the effects of countdown signals on driving behavior related to traffic safety and efficiency and encourages researchers at the micro and macro levels to explore the effects of countdown signals on traffic behavior and safety.

## Literature review

### Method

Relevant literature on driving behavior toward countdown-signalized intersections was researched and analyzed. Combination of keywords using words such as traffic safety, traffic efficiency with countdown signal, signal display, signal device, or timers. Resource databases (in both English and Chinese) related to transportation or traffic were selected. These sources primarily included the main databases of Elsevier (www.sciencedirect.com/), the American Society of Civil Engineers (http://ascelibrary.org/), Taylor & Francis (www.tandfonline.com/), John Wiley & Sons Inc. (http://onlinelibrary.wiley.com/), Springer–Verlag (www.springerlink.com), IEEE/IEE Electronic Library (http://ieeexplore.ieee.org/), CNKI of China ((www.cnki.net), and Wanfang of China (www.wanfangdata.com.cn/). The related literature was downloaded and reviewed, and the conclusions presented by these studies were compared.

### Characteristics of included literature and preliminary findings

A total of 46 papers related to driving behaviors about traffic safety and efficiency at countdown-signalized intersections were reviewed. The sources and quantitative characteristics of these studies are shown in Table 1.

As known from Table 1, several countries, including China, Thailand, India, Singapore, Malaysia, Greece, the US, and the UK, currently apply countdown signals at road intersections. Relatively speaking, China has previously adopted countdown signals (the authors of this paper live in China and know the application of countdown signals in China). In fact, these signals were employed 10 years ago in some cities in China. Currently, countdown signal lights are widely used in China, particularly in large urban centers such as Beijing, Guangzhou, Qingdao, and Jinan. However, countdown signals are not used at all intersections in all cities in China or other countries. Such insufficient application of countdown signals and other related reasons have led to a scarcity of studies on countdown signals and their effects on driving behaviors related to traffic safety and efficiency.

### Studies on green and red countdown signals

Countdown signals generally incorporate green and red signals, which may produce varying effects. In general, the countdown is shown by a device, such as a display or a timer. For convenience, abbreviate a signal countdown device (display or timer) to SCD, a green signal countdown device (display or timer) to GSCD, and a red signal countdown device (display or timer) to RSCD as well. Table 2 shows studies of the effects of GSCD and/or RSCD.

### Other studies on countdown signals

Some researchers did not specifically indicate whether their investigation aimed to explore the green or red countdown signal but focused on countdown signals in general, as shown in Table 3.

Countdown signals are used in some countries. However, the current standards or installation specifications are incomplete,

**Table 1.** The sources and quantitative characteristics of studies.

| Country | Total number | Number | Time |
|---|---|---|---|
| Malaysia | 2 | 1 | 2005 |
| | | 1 | 2008 |
| Singapore | 1 | 1 | 2006 |
| China | 32 | 1 | 2006 |
| | | 2 | 2008 |
| | | 3 | 2009 |
| | | 6 | 2010 |
| | | 3 | 2011 |
| | | 1 | 2012 |
| | | 3 | 2013 |
| | | 4 | 2014 |
| | | 2 | 2015 |
| | | 2 | 2016 |
| | | 1 | 2017 |
| | | 2 | 2019 |
| | | 1 | 2020 |
| | | 1 | 2022 |
| Korea | 1 | 1 | 2017 |
| Thailand | 2 | 1 | 2009 |
| | | 1 | 2010 |
| The US | 1 | 1 | 2018 |
| The UK | 1 | 1 | 2020 |
| India | 5 | 1 | 2012 |
| | | 1 | 2015 |
| | | 1 | 2017 |
| | | 1 | 2021 |
| | | 1 | 2022 |
| Greece | 1 | 1 | 2014 |

**Table 2.** Studies on GSCD and/or RSCD

| Study | Country | Study methodology | Content and/or results | Conclusions |
|---|---|---|---|---|
| Lum & Halim[5] (2006) | Singapore | Compared the red-running and red-stopping characteristics before GSCD installation with those obtained after GSCD started operation and used proportional tests to evaluate the statistical significance of the results. | Red-running violations were significantly reduced at 1.5 months after the installation of the GSCD, but the effectiveness of such a device dissipated over time and the violation numbers returned to almost pre-GSCD level. | The long-term performance of the GSCD only encourages the layoff of red violations but does not curb them. |
| Wang & Yang[6] (2006) | China | A questionnaire survey was conducted on 377 drivers in Longyan City, Fujian Province, to analyze their behavior choices and calculate the start delay time based on the survey results. | GSCD partially provoked drivers to accelerate through the intersection at the end of the green signal, which may cause severe intersection accidents. | GSCD must be set cautiously. |
| Yuan et al.[7] (2009) | China | The method used in this study focuses on comparative parallel research, collecting driver behavior characteristics of 4 countdown intersections and 4 non-countdown intersections in Nanjing, and comparing and analyzing the average values of the results. | The countdown displays significantly affected the decision of the motor vehicle drivers, and the red-running violations were reduced without GSCD. By contrast, the start-up delay was increased without RSCD. | Countdown signal lights must be installed cautiously. |
| Chiou & Chang[8] (2010) | China | Three driver responses to GSCD (late-stopping ratio, dilemma zone, and decision to cross) and three driver responses to RSCD (early start ratio, start-up delay, and discharge headway) were observed and analyzed in Taiwan Province. | Although GSCD can reduce late-stopping ratio, the dilemma zone is increased by about 28m, and the decision to cross will be more inconsistent among the approaching vehicles, creating a potential risk of rear-end crashes. | RSCD enhances intersection efficiency. RSCD is clearly less controversial and more beneficial than GSCD. |
| Ma et al.[9] (2010) | China | Investigated the impact of GSCD installation on the speed distributions for vehicles passing the stop line during the amber time and calculated the Dilemma Zone Distribution. | GSCD encouraged motorists to pass the stop-line during the amber time with greater speed. Such circumstances resulted in better utilization of the amber time and increased capacity for the intersection approach. | The GSCD can moderate the response of motorists toward phase transition, effectively prevent sudden speed change, and significantly reduce the number of red-light violations. |
| Qian & Han[10] (2010) | China | A questionnaire survey was conducted on 390 drivers, and the driving behavior of 250 rear vehicles under the GSCD was observed. | A considerable number of drivers chose to accelerate and rush over at the end of GSCD, crossing the intersection before the end of GSCD, resulting in the occurrence of speeding and rushing, leading to the need to set longer green light intervals. | GSCD is not good for either traffic safety or traffic efficiency. GSCD must be used with due consideration. |
| Qian[11] (2011) | China | A questionnaire survey was conducted on 390 drivers, and observations were conducted at two intersections with and without RSCD to study driving behavior and vehicle headway. | Under the condition of RSCD, the average loss time of vehicles passing through the intersection can be saved by about 1.5 s. | RSCD can reduce start-up lost time, calm driver emotions, and reduce fuel consumption. |
| Zhu et al.[12] (2012) | China | Collected driving behavior and speed data at SCD intersections and used descriptive statistics, analysis of variance, contingency tables, and other statistical methods to analyze the impact of signal control on speed and traffic. | The GSCD significantly affected excessive speed rates, and the RSCD considerably influenced speed dispersion. | Installing traffic violation detection equipment while using GSCD can effectively control vehicle speed. |
| Lin et al.[13] (2013) | China | Two similar intersections with and without countdown signals were selected as the research subjects, and a one-way ANOVA was used to evaluate whether countdown signals have a significant impact on reducing the occurrence of dilemma zones. | The dilemma zones mostly occurred at a distance of 30 to 75 m from the stop line at the intersection. The majority of drivers took conservative measures such as "parking" when facing the hesitation zone at the intersection while driving the vehicle. | GSCD has a significant effect on cutting down the range of dilemma zones. |
| Huang et al.[14] (2014) | China | The influence of three typical signal devices with various time-reminder strategies, i.e., common signal device (CSD), green signal flashing device (GSFD), and GSCD, on drivers' decision-making processes during the period from the end of the green phase to the onset of the red phase was analyzed, and their safety performance from the aspect of red-light-running (RLR) violations was evaluated. | Stop and go decisions under GSCD, stop and go decisions under GSFD and go decisions under CSD are all significantly different from stop decisions under CSD regarding their effects on RLR violations of vehicles in DZ. The odds of RLR violations for these five conditions were respectively, 11.815, 4.144, 2.452, 1.214, and 3.439 times as large as those for stop decisions under CSD. | Although GSCD stimulates the drivers in dilemma zones to choose to cross the intersection during amber, which produces a higher RLR risk compared with CSD and GSFD, the intersection with GSCD is verified to own the lowest RLR violations due to its greatly positive effect in cutting down the range of dilemma zones. |

(to be continued)

**Table 2.** (continued)

| Study | Country | Study methodology | Content and/or results | Conclusions |
|---|---|---|---|---|
| Ni & Li[15] (2014) | China | Based on the field observation carried out at 2 GSCD intersections and 2 NGSCD intersections (i.e., intersections without GSCD devices) along an arterial in Suzhou, the rear-end probabilities at GSCD and NGSCD intersections were calculated using Monte Carlo simulation. | On the one hand, GSCD caused significantly negative safety effects during the flashing green interval, especially for vehicles in a zone ranging from 15 to 70 m; on the other hand, GSCD was helpful in reducing rear-end accidents during the yellow interval, especially in a zone from 0 to 50 m. | GSCD can shorten indecision zones and reduce rear-end collisions near the stop line during the yellow interval, but it easily results in risky car following behavior and much higher rear-end collision probabilities at indecision ones during both flashing green and yellow intervals. |
| Cao et al.[16] (2015) | China | Selected two countdown signal intersections and two non-countdown signal intersections in Dalian city, and used mathematical statistical methods to compare and analyze the vehicle speed characteristics, as well as the number of yellow light running and lane changing violations, of the two types of intersections during normal and peak hours. | The countdown signal has a smaller impact on vehicle behavior of running yellow lights, while the countdown signal has a significant impact on illegal lane changing behavior. | GSCD can induce some drivers to speed through intersections at the end of green light time, and has a significant influence on the number of illegal changing lane behaviors at off-peak hours. |
| Yang et al.[17] (2015) | China | The differences between the first vehicle start up delay under situations of with-without RSCD, turning left and going straight vehicles were analyzed respectively by nonparametric test. | There was significant difference for the first vehicle start-up delay between countdown and non-countdown signalized intersections ($p = 1.83 \times 10^{-5}$). | Intersections with RSCD significantly reduce the delay in starting the first vehicle compared to intersections without a RSCD. |
| Devalla et al.[18] (2015) | India | Observations were conducted at intersections in New Delhi with or without signal control, and extracted data was analyzed to assess the effect of GSCT on RLV and variations of vehicular speeds both in the presence and absence of timers. | GSCD is found to be linked with fewer red-light violations (RLVs) cycles, lower number of mean RLV per RLV cycle, higher vehicular speeds during the phase transition at different locations upstream to the stop line, a greater number of speeding cars, and higher stop line crossing speed during amber. | GSCD encourages drivers to travel at higher speeds, which could lead to accidents. |
| Biswas et al.[19] (2017) | India | This study evaluated the influence of SCTs on intersection efficiency and safety by conducting "before and after" study at three signalized intersections located in New Delhi. | The presence of RSCT led to higher RLVs during the last 10 s of red. It was observed that the ranges of both Type I and Type II DZs for small cars reduced in the presence of GSCT. | GSCT has no impact on saturated flow. Although RSCT can help reduce startup lost time, it can increase accident risk. |
| Huang et al.[20] (2019) | China | In summer (normal road surface) and winter (road surface snow state), the approach speed, stopping or passing ratio, and maximum deceleration braking area of the target vehicle were collected and analyzed using video recording methods. | Comparing the maximum deceleration models of intersections under three types of signal configurations in winter and summer, it can be found that the countdown signal can enable vehicles to slow down and brake earlier when approaching the intersection, stopping at a safe and stable deceleration. | The countdown signal light helps the vehicle decelerate smoothly, especially on icy roads in winter, enabling the driver to make a stop decision earlier and reducing the occurrence of sudden braking. |
| Paul & Ghosh[21] (2020) | The UK | Evaluate the effectiveness of the green signal countdown timer (GSCT) for RLV and the resulting right angle and right turn related crashes (for left hand driving) using post encroachment time (PET). | Using GSCT reduced cross-conflict by 2.57%. | GSCT's installation can be recommended as a cost-effective engineering countermeasure to reduce severe crash types at signalized intersections. |
| Paul et al.[22] (2022) | India | Collected collision data and on-site traffic data, and used the PTV VISSIM micro simulation tool to simulate intersections with and without GSCT signal control to conduct conflict analysis for various situations. | The GSCT was found to influence driving behaviors at yellow onset, shorten the length of both type-I and type-II DZ, and reduce the rate and intensity of both RLVs and sudden stopping behaviors. | The setting of GSCD is beneficial for traffic safety. |
| Liu et al.[23] (2022) | China | Collected traffic flow characteristics data for two types of intersections with and without green countdown signals, mainly including location speed, vehicle start time, and headway data. Based on behavioral decision-making theory, a logistic model was constructed to evaluate the impact of green countdown signals on driver driving decisions. | The GSCD prompted the driver to slow down. The probability of vehicle acceleration behavior at intersections with GSCD was lower than that at intersections without GSCD, and the probability of parking behavior was higher than that at intersections without GSCD. | The GSCD has a certain positive effect on the safety and traffic efficiency of intersection driving. |

particularly for motorized vehicle countdown signals. In China, the 'National Standard of Road Traffic Lights' (Ministry of Public Security of the People's Republic of China, 2003) and 'National Specification for Setting and Installation of Road Traffic Signals' (Ministry of Public Security of the People's Republic of China, 2006) do not cite the methods of using and setting countdown

**Table 3.** Studies on countdown signals.

| Study | Country | Study methodology | Content and/or results | Conclusions |
|---|---|---|---|---|
| Kidwai et al.[24] (2005) | Malaysia | The effect of countdown timers on red-light violations was studied. Four intersections with timers and three intersections without timers were considered, and red-light violation data were compared. | The incidents of red-light running were about two times higher in cases without countdown timers than in cases with countdown timers. | Compared to no signal control, countdown signals can reduce the phenomenon of red-light violation. |
| Ibrahim et al.[25] (2008) | Malaysia | Six intersections (three with countdown timers and three without) were analyzed to examine the effect of countdown timers on driving behaviors, intersection approach headways, and safety levels. | The digital timer had a significant effect on discharge headway for all the cars in queue. The rate of red-light violation is more for count down intersections than for non-count down ones. | Countdown signals are not as safe as no countdown signals. |
| Limanond et al.[26] (2009) | Thailand | The influence of countdown timers installed at a signalized intersection on the queue discharge characteristics of through movement during the green phase in Bangkok was studied. Standard statistical t-tests were used to compare the difference in traffic characteristics between the "with timer" and "without timer" cases. | During the periods where the timer was in use, the mean saturation headway gradually increased from 1.88 s/vehicle during the off-peak daytime, to 1.94 s during the night period, and finally to 2.05 s during the late-night period. Similarly, for the condition without a timer, the mean saturation headway progressively increases from 1.85 s/vehicle during the off-peak daytime to 2.05 and 2.09 s for the nighttime and late-night time periods, respectively. | Countdown timers significantly affect the start-up lost time. For each through movement lane at the studied intersection, the savings in start-up lost time were estimated to equal an increase of 8 to 24 vehicles per hour. However, the effects on saturation headway were minimal. |
| Limanond et al.[27] (2010) | Thailand | The traffic analysis made a comparison of traffic characteristics during an off-peak time at a selected intersection when the countdown timer was in operation against when it was switched off, and a public opinion survey was conducted on more than 300 regular local drivers. | The presence of the countdown timers at the intersection would help to reduce the start-up lost time at the beginning of the green phase by 22%, and reduce the number of red-light violations during the beginning of the red phase by 50%. | Countdown timers can reduce the start-up lost time and reduce the number of red-light violations. And the majority of the local drivers were favorable towards the countdown timers. |
| Sharma et al.[28] (2012) | India | The changes in queue-discharge characteristics and red-light violations were analyzed under Indian traffic conditions with the presence of a timer. A before-and-after analysis was conducted using the data collected from a selected intersection in Chennai. | It was found that the propensity of RLV decreased from 59% to 31% at the start of red and increased from 12% to 75% at the end of red. Also, the intensity of RLV for both the start of red and the end of red decreased from 3.32 to 2.30 vehicles and 8.52 to 5.60 vehicles. | The time information provided at the start of the green light (end of the red light) enhances efficiency and reduces start-up lost time, but increases red-light violations. |
| Wang[29] (2008) | China | It introduced the current status of traffic signal countdown equipment in China and abroad, and qualitatively analyzed the advantages and disadvantages of countdown signals. | GSCD tended to trigger speeding, and GSCD reduced delays and improved roadway capacity. | It is recommended that a countdown for red lights be used, and that no countdown be used for green and yellow lights. |
| Ma[30] (2008) | China | The camera method was used to observe the behavioral differences of drivers at intersections with and without countdown signals. The logistic model was used to establish a behavioral decision-making model for drivers at countdown signal intersections. | The countdown signal showed that the remaining 1 second is the decision point for the driver's acceleration or constant speed behavior. At intersections without countdown signals, the speed at a distance of 20m from the parking line should be controlled within the range of 13–22 m/s. | Countdown displays significantly affect the decision-making behavior of motorists. And the number of traffic conflicts increases at intersections with countdown displays. |
| Wu et al.[31] (2009) | China | Based on the two aspects of vehicle types and speed, a logistic model was used to construct the model of behavioral decision at countdown-signalized intersections. | The sensitivity of "signal light display time" to uniform speed behavior was the strongest. The second was deceleration behavior. The sensitivity of acceleration behavior was relatively lower than the first two. | Countdown signal display remarkably influences the decision-making behavior of motorists. |
| Zhang et al.[32] (2009); Zhang et al.[33] (2010) | China | The survey collected 20 survey questionnaires from drivers and pedestrians to understand the opinions of traffic participants on countdown signal lights, and observed driving behavior for 7 consecutive days before and after the installation of countdown signal lights in Beijing. | The survey results showed that over 85% of drivers and pedestrians are willing to choose signal control methods with countdown display. The $Z_{stat}$-test showed whether there is a significant decrease in yellow light passing behavior after countdown installation compared to when not installed at a 95% confidence level. | Traffic volumes were considerably similar before and after the countdown signal was installed. Meanwhile, the yellow-crossing and red-light running incidents significantly decreased after the countdown signal was installed. |

(to be continued)

**Table 3.** (continued)

| Study | Country | Study methodology | Content and/or results | Conclusions |
|---|---|---|---|---|
| Gong[34] (2010) | China | The driving behaviors of motorists in red-light running at six countdown-signalized intersections were explored and analyzed the rate of this type of incident. | The red-light violation rate at intersections with countdown was slightly higher than that at intersections without countdown. | Installing a countdown timer must be considered carefully. |
| Li & Wang[35] (2010) | China | An analysis was conducted on the light color regulations in urban road traffic signal control in China and the influencing factors of some commonly used signals in both positive and negative aspects. | They analyzed some problems in Chinese urban road traffic signal control and stressed that motorized vehicle countdown signals didn't provide other benefits except psychological comfort to drivers. Such signals even endangered traffic safety. | These researchers don't recommend the use of motorized vehicle countdown signals. |
| Long et al.[36] (2011) | China | The researcher surveyed the signal phase and traffic operation at four signalized intersections and collected 24-hour red light time, driver's position and actions after yellow light appearance, red light violation driving, and other intersections with and without countdown timers. Measured driver behavior through driver decisions (parking or driving) and vehicle entry using binary logistic regression (BLR) and non-parametric testing. | Countdown timers can indeed influence driver behaviors, in terms of decisions to stop or cross the intersection as well as the distribution of vehicle entry times. There was a strong correlation between the presence of countdown timers and an increase in red light violations. | Countdown timers may lead to entering intersections in the later stages of yellow or even red, so consider carefully before deploying countdown timers at intersections. |
| Long et al.[37] (2011) | China | Data were collected at three intersections with and without countdown signals, and binary logistics regression was applied to establish the driver decision type selection model after the yellow light was on. | With the installation of the countdown timer, the average vehicle crossing time has increased from 1.52 to 2.92 s. | Countdown signals have an adverse effect on the safety of intersections. |
| Long et al.[38] (2013) | China | The difference in driver's stop/go decisions at the countdown and non-countdown timer installed intersections were investigated with binary-logistical regression analysis. | The probability of driver choosing to stop at a countdown timer equipped intersection was only 0.282 times of that at a non-countdown timer intersection when the signal turned red. | Countdown timer can better assist drivers in their decision-making process and thus may reduce hazardous driving maneuvers during the phase transition period. |
| Li et al.[39] (2014) | China | Drivers' perception–reaction time (PRT) with and without a countdown timer were comparatively analyzed based on the RGB color model and the fuzzy c-means clustering was utilized for PRT classification and comparison. | The drivers' PRT was decreased from 2.12 to 1.48 s with countdown signals. | The countdown signal significantly shortens the driver's PRT. |
| Papaioannou & Politis[40] (2014) | Greece | A survey was conducted at an intersection in the city of Komotini, Greece, with or without a countdown signal timer (CST). A total of 60 h of observation time were recorded to observe vehicles' movement characteristics. | The percentage of the violations of the early start at the intersection with SCD was observed to 24% whereas the respective percentage for the intersection without SCD was less than 1%. | The CST devices (with green signal countdown displays-GSCD-and red signal countdown displays-RSCD), should be carefully used since they tend drivers to early start behavior. |
| Sun et al.[41] (2013) | China | Data collection was conducted in Guangzhou, collecting raw video data from 36 h of peak hours on weekdays. Discovering the effects of countdown timer on capacity and headway. | The countdown timer decreased the headway fluctuation of vehicles in the queue, with the standard deviation reducing by 10% to 25%. And the capacity of the through movement improved by about 5% to 10% after the countdown timers were installed. | Countdown signal can reduce the mean headway of vehicles and increase road capacity. |
| Yu et al.[42] (2014) | China | The study collected relevant data from 9 signalized intersections and a total of 13 entry lanes, using the situation of vehicles passing through parking lines and the number of traffic conflicts during the red and yellow light periods as alternative safety evaluation indicators. The data on the entry lanes of intersections with and without signal countdown devices were compared. | In both straight and left turn directions at the intersection, the frequency of adventurous traffic and the number of traffic conflicts at the intersection entrance have significantly increased due to the influence of signal countdown devices. | SCD significantly increases the red-yellow running violation and traffic conflicts at signalized intersections for both through and protected left turn movements. SCD negatively affect the safety performance of the signalized intersections and should be used more cautiously. |

(to be continued)

**Table 3.** (continued)

| Study | Country | Study methodology | Content and/or results | Conclusions |
|---|---|---|---|---|
| Zou[43] (2016) | China | Based on video data, parameters such as driver's response time to start, headway, and vehicle retention rate in weaving areas during yellow light periods under different commutation prompts were extracted to analyze the effectiveness of the countdown signal. | The driver's reaction time at intersections with countdown signal lights has been reduced by 14.51%, and the time when vehicles pass the parking line has been advanced by 9.85% after reaching the saturation headway. During the yellow light period, the vehicle retention rate in the weaving area has increased by 38.68%. | The countdown signal commutation reminder device can improve the operational efficiency of intersections, but may have a certain potential negative impact on intersection traffic safety. |
| Ma et al.[44] (2017) | China | Based on the measured data, the speed distribution characteristics of each section of the signal-controlled entrance road were analyzed, and a cellular automata model considering driving psychology under signal countdown was proposed. | At an intersection with a countdown signal 14m away from the stop line, the driver acceleration ratio was 19%. | Countdown signals are not conducive to traffic safety and may cause traffic hazards. |
| Chang & Jung[45] (2017) | Korea | Using a driving simulator, 20 traffic lights with countdown indicators were compared from the perspectives of driver reaction time and subjective satisfaction scores, and their performance was compared with standard traffic lights. | The reaction time of the countdown separation (43.0 s) and countdown superposition (67.5 s) signals was significantly shorter than that of the standard signal (3.5 s). The satisfaction score of the countdown separation (6.3 points) and countdown superposition (8.0 points) signals was higher than that of the standard signal (06.0 points). | Countdown signals can shorten the driver's reaction time more than standard signals, helping to reduce the length of dilemma areas at intersections. |
| Almutairi[46] (2018) | The US | Analyzed the impact of signal timers on startup loss time (SLT), saturation time interval (STH), and the location and size of difficult areas, and modeled the observed maximum passing and minimum stopping distances based on real ground data. | The quantified different effects from the intersection with no timers or camera enforcement for the saturation time headway were −0.02, 0.02, and −0.07 seconds for timers, camera enforcement, and both, respectively. The quantified different effects from the intersection with no timers or camera enforcement for the startup lost time were −1.65, −0.41, and −0.88 for timers, camera enforcement, and both, respectively. | Countdown lights improve security by reducing SLT and minimizing the size of difficult areas. |
| Huang et al.[47] (2019) | China | Six intersections in Shenyang were selected to analyze the behavior of vehicles under countdown signals in summer (normal road surface) and winter (road surface snow state). Based on the processed data, a distribution map and a start delay model were established. | In summer and winter, the average maximum deceleration of intersections with countdown signals was approximately 1.0 $m/s^2$ lower than that of intersections without countdown signals. | Countdown traffic signals can shorten the start delay and improve traffic efficiency and safety at intersections. |
| Zheng et al.[48] (2020) | China | Based on on-site shooting data of typical signalized intersections in Beijing, the impact of countdown signals on pedestrian and non-motorized vehicle gap acceptance behavior was studied using methods such as nonlinear fitting and hypothesis testing. | Under normal signals, the average acceptance gap between pedestrians and non-motorized vehicles was 9.0 s, while under countdown signals, it was 7.3 s. | Under the countdown signal, the acceptance gap value of pedestrians and non-motor vehicles significantly decreases, and the probability of collision increases. |
| Jatoth et al.[49] (2021) | India | Research was conducted at two intersections in Hyderabad, India, to collect and analyze data such as vehicle startup loss time and capacity. | The number of red-light violations (RLVs), start-up lost time, and average control delay are found to decrease in the presence of an active countdown timer. | The signal countdown timer is an effective device that can enhance the traffic safety and operational performance of a signalized intersection. |

signals[50,51]. The main reason for this instance is an inadequate understanding of the mechanism of the effect of countdown signals on driving physiology, psychology, and behaviors. In the United States, the 'Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), 2009 Edition' provides the basic guidelines (Federal Highway Administration, 2012) for adopting and installing countdown pedestrian signals[52]. However, the MUTCD (2009) states that vehicular countdown displays or other similar displays are not to be used at signalized locations.

## Discussion

This review identifies that the related literature on countdown signals mainly emphasizes the driving behaviors of red-light running and early starting-up or headway for traffic efficiency. Red-light running behavior is determined to be closely related to traffic safety.

In particular, the existing literature adopts two main research methods. One method employs on-site observations or video recorders to acquire data on running red lights or potentially dangerous rear-end collision behavior at intersections with and without countdown signals. After data are obtained, the safety situation of the intersection is analyzed. Based on the review, the studies posited significantly different conclusions. For the occurrence probability of red-light running, the conclusions are inconsistent, as shown in Table 4.

In addition, by considering the potential risks of countdown signal control, Wang & Yang[6]; Qian & Han[10]; Gong[34]; Long et al.[37]; Qian[11]; Long et al.[36]; Ni & Li[15] suggested that countdown signals must be used cautiously. By contrast, Li & Wang[35] refused to recommend the use of motorized vehicle countdown signals.

The second research method used by the related studies is that which adopts on-site observations or video recorders to obtain data on intersection vehicle start-up lost time, start-up delay, or approach headway to assess the effects of countdown signals on traffic efficiency. For start-up lost time, delay, headway, and so on, the conclusions are shown in Table 5.

As shown in Table 5, the majority of the researchers believe that the countdown signals can improve traffic efficiency. The unity of the cognition of traffic efficiency is obviously better than the consensus on traffic safety.

Summarizing the existing research findings on countdown signals, we observe two basic attitudes. The first is a supportive attitude, which denotes that the countdown signal can improve traffic safety and efficiency. The other is the negative attitude, which indicates that countdown signals can increase the occurrence of traffic accidents. The conclusions of the extant literature reasonably vary because of a remarkable disparity between the intersection traffic environments in different geographical areas and because driving behaviors may vary significantly among countries. A related concern is the insufficient research and lack of in-depth studies on driving behaviors at countdown-signalized intersections, as well as the limited diversity of such studies. Thus, determining the advantages and disadvantages of countdown signals is difficult.

It is worth noting that, for traffic safety, at present no studies have used the number of traffic collisions or collision rate to explain the increase or decrease of collisions after the application of the countdown signals on the road network. The cause may be a lack of collision data. However, this is a potential research field.

The application of motor vehicle countdown signals is related to many aspects at different levels, such as driving psychology, driving behavior, vehicles, traffic safety, and traffic efficiency. Currently, every aspect needs to be fully studied. Researchers in different countries must explore the effects of countdown signals on motorists driving behaviors, intersection safety, and traffic efficiency, which may be of concern to many people. More studies must also be conducted in different geographical locations to develop comprehensive standards for countdown signals.

## Proposal for further studies

Although some researchers have realized that the application of countdown signals may generate different effects and

**Table 4.** The opinion of different studies on traffic safety.

| Studies | Opinion | Impact on traffic safety |
|---|---|---|
| Kidwai et al.[24] (2005); Zhang et al.[32] (2009); Zhang et al.[33] (2010); Ma et al.[9] (2010); Limanond et al.[27] (2010); | The researchers believed that red-running violations are reduced with countdown signals. | Positive |
| Sharma et al.[28] (2012); Yuan et al.[7] (2009); Yu et al.[42] (2014) | The researchers deemed that red-running violations increase with countdown signals. | Negative |
| Zheng et al.[48] (2020) | Researchers believed that under timing signals, the probability of collision increases | Negative |
| Lum & Halim[5] (2006) | The authors attested that red-running violations initially decrease and then increase after a GSCD is installed. | First positive, then negative. |
| Zou H[43] (2016); Ma et al.[44] (2017); Biswas et al.[19] (2017) | The countdown signal commutation reminder device can improve the operational efficiency of intersections, but may have a certain potential negative impact on intersection traffic safety. | First positive, then negative. |
| Lin et al.[13] (2013); Huang et al.[14] (2014); Chang & Jung[45] (2017); Almutairi[46] (2018); Paul et al.[22] (2022) | GSCD have a positive effect on cutting down the range of dilemma zones. | Positive |
| Paul & Ghosh[21] (2020); Liu et al.[23] (2022) | Using GSCT can reduce cross conflict and traffic accident. | Positive |
| Zhu et al.[12] (2012); Devalla et al.[18] (2015) | GSCD encourage drivers to travel with higher speed which could lead to accidents. | Negative |

**Table 5.** The opinion of different studies on traffic efficiency.

| Studies | Opinion | Impact on traffic safety |
|---|---|---|
| Ibrahim et al.[25] (2008) | Countdown timers moderately affect initial delay but significantly influence headway. | Positive |
| Limanond et al.[26] (2009); Huang et al.[47] (2019) | Countdown timers significantly affect the start-up lost time. However, the effects on saturation headway were minimal. | Positive |
| Chiou & Chang[8] (2010); Qian[11] (2011); Li et al.[39] (2014); Yang et al.[17] (2015); Xu et al.[53] (2016) | The researchers deemed that start-up lost time reduction and traffic efficiency improvement. | Positive |
| Ma et al.[9] (2010); Sun et al.[41] (2013); Jatoth et al.[49] (2021) | The authors supposed that countdown timer could increase the traffic capacity. | Positive |
| Long et al.[37] (2011) | The authors determined that the median value of the time a vehicle crosses a stop bar with a countdown timer is significantly. higher than that without a countdown timer. | Positive |
| Qian & Han[10] (2010) | GSCD is not good for either traffic safety or traffic efficiency. | Negative |

some related studies have been carried out, there are still a lot of studies in different aspects that need to be performed in the future. What are the factors involved in the timing of signals when applying the countdown signals? What are the requirements for the allocation of lanes to traffic movements? What are the differences in the application of countdown signals between the fixed-time signal road net and the traffic-responsive road net? What is the impact of the countdown signals on the application of the intelligent transportation system? And, as mentioned in the discussion, the risk of collisions of various types resulting from countdown signals needs to be analyzed, and how do we to use collisions to evaluate the application of the countdown signals? Many problems need to be studied and solved in the future.

However, the authors of this paper are more concerned with future microcosmic studies related to driving behavior. Existing studies on the effects of countdown signals on driving behavior and intersection safety are still at the macro level of shallow qualitative analysis and description, and the number of microcosmic studies remains insufficient. In particular, quantitative analysis of specific micro-data combined with macro-data is inadequate. Moreover, the source of information in existing studies is single, such as only using macroscopic data on the driving behavior of running a red light and not using microcosmic psychological data at this time, indicating a lack of multi-source or multi-level information data.

Driving physiology and psychology are closely related to driving behaviors, in other words, the driving behaviors are the result of the interaction between the physiology and the psychology. At present, driving physiological and psychological changes at countdown-signalized intersections have not been explored quantitatively. Therefore, more advanced technologies and devices must be adopted to thoroughly understand driving behaviors so that data on driving physiology and psychology at countdown-signalized intersections can be obtained and driving behaviors with particular indicators can be characterized. Accordingly, microcosmic performance is combined with macro driving behaviors, in which the microscopic in-depth effect of countdown signals on driving behaviors is analyzed, thereby achieving the further effect of countdown signals on intersection safety.

Current scientific technologies provide support for microscopic studies. For example, the MindWare System can measure the electrocardiogram (ECG), electromyogram (EMG), galvanic skin conductance (GSC), and other physiological parameters of drivers. The instrument is displayed in Figs 2 & 3.

Driving behaviors at countdown-signalized intersections are affected by many factors. The information obtained from a single source cannot fully reflect the reality. A valid and complete description of driving behavior characteristics can be acquired by collecting multiple sources of information and performing multivariate analysis. Different levels of information must be applied to complement each other and reflect the actual situation.

For countdown-signalized intersections, the following steps or ideas for micro-level studies on drivers must be considered in future research:

Step 1. A number of drivers, both male and female, with different driving experiences, should be selected. In theory, a large number of drivers can reflect the actual situation.

**Fig. 2** Main hardware for measuring physiological parameters.

**Fig. 3** Main software for measuring physiological parameters.

Step 2. The equipment to test driver physiology, psychology, and behavior on the experimental vehicle should be installed.

Step 3. A suitable road route with multiple intersections with and without the countdown signal should be selected.

Step 4. In the pre-selected time, different motorists should be instructed to drive the test vehicle in accordance with the selected route. In this process, the instrument records the microcosmic data, reflecting the driver's physiology, psychology, and macroscopic behavior when the driver passes through the intersections with and without the countdown signal.

Step 5. The data should be processed and analyzed.

Step 6. The consistency and differences in driver behavior when passing through the intersections with and without countdown signals should be determined.

Step 7. According to the results, proposals for countdown-signalized intersection safety and efficiency and proper usage of countdown signals should be offered.

The future research process is described in the block diagram presented in Fig. 4.

## Conclusions

This review analyzes and summarizes the related literature on the effects of countdown signals on driving behaviors related to traffic safety and efficiency. Accordingly, this review identifies that the extant literature presents different conclusions on traffic safety, especially about the behavior of red-light running. Propositions on traffic efficiency are not completely consistent. In particular, research conclusions are different, which implies a possible distinction between the intersection traffic environments in different geographical regions and the potentially wide variation in driving behaviors in different countries. Moreover, this review determines that the number of

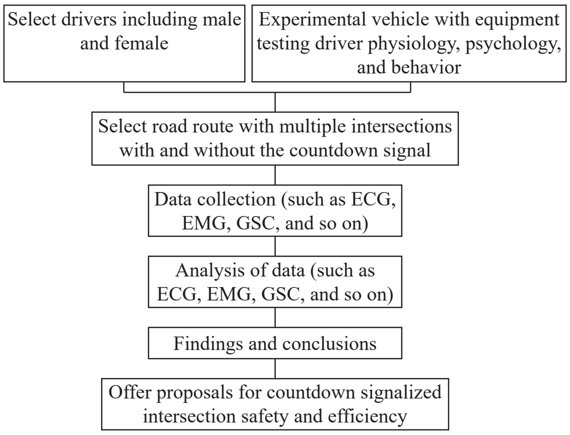


**Fig. 4** Future research framework.

current studies on driving behaviors at countdown-signalized intersections is insufficient, and the lack of diversity in research causes difficulty in completely evaluating the benefits and disadvantages of countdown signals.

This review gives a number of aspects of future studies and suggests the use of new technologies and equipment to obtain microcosmic driving psychological and physiological data on motorist behavior when passing through countdown-signalized intersections. The characteristics of driving behaviors must be described with an appropriate index, and further microcosmic performance must be combined with macro driving behaviors to comprehensively analyze the effects of countdown signals on driver behaviors. This review presents comprehensive insights into the existing microscopic studies on driver behaviors toward countdown-signalized intersections.

## Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Pan F; literature collection and summarization: Pan F, Yang JZ; analysis and interpretation of results: Zhang L, Yang J; draft manuscript preparation: Ma C, Zhang P.

## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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## Conflict of interest

The authors declare that they have no conflict of interest. Fuquan Pan and Changxi Ma are the Editorial Board members of *Digital Transportation and Safety* who were blinded from reviewing or making decisions on the manuscript. The article was subject to the journal's standard procedures, with peer-review handled independently of these Editorial Board members and their research groups.

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