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Research Article

Impact of Vehicular Countdown Signals on Driving Psychologies and Behaviors: Taking China as an Example

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Countdown signal control is a relatively new control mode that can inform a driver in advance about the remaining time to pass through intersections or the time needed to wait for other drivers and pedestrians. At present, few countries apply vehicular countdown signals. However, in China, some cities have applied vehicular countdown signals for years, though it is unclear how and how much such signals influence driving psychologies and behaviors compared with non-countdown signal controls. The present work aims to clarify the impact of vehicular countdown signals on driving psychologies and behaviors on the cognitive level. A questionnaire survey with 32 questions about driving psychologies and behaviors was designed, and an online survey was conducted. A total of 1051 valid questionnaires were received. The survey data were analyzed, and the main results indicate that most of the surveyed drivers prefer countdown signal controls and think that such controls can improve not only traffic safety but also traffic operational efficiency. The surveyed drivers also think that countdown signal controls have an impact on driving psychologies and behaviors and the survey results have demonstrated that the driving behaviors of female drivers surveyed are not conservative under the clear conditions of green countdown signal control. Further studies and methods concerning the effects of countdown signals on driving psychologies and behaviors are discussed.

1. Introduction

While intersections are part of the road system, they are far more complex than the segments connecting them [1, 2]. Driving psychologies and behaviors at road intersections are considerably different compared to those at road sections. According to the control mode, there are two kinds of road intersections: unsignalized and signalized. In recent years, countdown signalized intersections have appeared in some countries or areas. Compared to traditional non-countdown signals, countdown signals can inform a driver in advance about the remaining time to pass through intersections or the time needed to wait for other drivers and pedestrians. Countdown signals can be divided into vehicular countdown signals and pedestrian countdown signals. Vehicular countdown signals further include green, red, and yellow countdown signals.

Out of more than 200 countries, only a few use countdown signal controls at road intersections, such as China, Thailand, India, Singapore, Malaysia, the United States, and the United Kingdom. Of these countries, only a small number allow pedestrian countdown signals to be used at road intersections, such as the United States and Britain. In other words, few countries currently use vehicular countdown signals. The object of this study is to focus on vehicular countdown signals.

China, as one of the pioneer countries, is playing a leading role in the use of vehicular countdown signals. However, no specific manuals or standards are available for guiding the usage of vehicular countdown signals in China [3–5]. Therefore, Chinese local governments encounter difficulties in making a clear decision on extending the application of vehicular countdown signals. Traffic engineers and researchers have different opinions on the application of vehicular countdown signals. Some support the use of countdown signal controls and consider such controls as capable of improving traffic operational efficiency by taking full advantage of the signal time. Others are opposed to the application of countdown signal controls and are concerned about the possibility of such controls increasing traffic crashes and having a negative impact on traffic safety [6].

In theory, vehicular countdown signals are different compared to non-countdown signals and should have an impact on driving psychologies and behaviors. However, to date, it is unclear how and how much vehicular countdown signals influence driving psychologies and behaviors compared with non-countdown signal controls. To answer these questions, the present study explored the influence of vehicular countdown signals from two aspects of driving psychologies and behaviors based on a questionnaire survey. The survey consisted of 32 questions related to vehicular countdown signals.

2. Literature Review

This paper focuses on vehicular countdown signals (hereafter referred to as countdown signals in the following text unless specified otherwise). To date, countdown signal control, as a new traffic control mode of signalized intersections, is applied in China, Singapore, Thailand, Malaysia, India, and other countries. Lum and Halim conducted a before-and-after study by observing driver reactions at a signalized intersection with a green signal countdown display (GSCD) installed [7]. The finding revealed that the number of red-light running violations is significantly mitigated at the initial period after installing the GSCD. However, the effectiveness of the device tends to dissipate over time, with the number of violations bouncing back to almost the same level as before GSCD. Ibrahim et al. introduced countdown timers installed at some intersections in Kuala Lumpur, Malaysia [8]. The impact of countdown timers on driving behaviors and intersection approach headways was studied by comparing three intersections with countdown timers with three intersections lacking countdown timers. The result indicated that the countdown timers have a significant impact on headways but a little impact on the initial delay. Limanond et al. studied how countdown timers affect the queue discharge characteristics of through movements during the green phase at a signalized intersection in Bangkok, Thailand [9]. They pointed out that the countdown timers had a significant impact on the start-up lost time at the intersection under study, but the effect on the saturation headway was negligible. Chiou and Chang investigated the impact of GSCD and red signal countdown display (RSCD) on driver behaviors in Taiwan [10]. The results showed that GSCD can reduce the late-stopping ratio, but it increases the likelihood of rear-end crashes. Although RSCD can effectively reduce the start-up delay, saturated headway, and cumulative start-up delay, it cannot significantly improve intersection safety in the long term. Sharma et al. presented the usage of countdown timers at signalized intersections in India [11]. The study conducted a before-and-after analysis by comparing predata with postdata collected at a selected intersection in Chennai. The results reflected that the time information provided at the beginning of the green light (end of the red light) can enhance efficiency and reduce start-up lost time but increase red-light running violations. Papaioannou and Politis found that the percentage of early start violations at the intersection with SCD was 24%, where the percentage for intersections without SCD was less than 1% [12]. Devalla et al. found that GSCD is linked with fewer red light violations (RLVs) cycles, a lower mean number of RLVs per RLV cycle, higher vehicular speeds during the phase transition at different locations upstream to the stop line, a higher number of speeding cars, and higher stop line crossing speeds during amber [13]. Islam et al. found a reduction in start-up lost time at signalized intersections when a red signal countdown timer is present [14].

In China, Wang and Yang conducted a preliminary analysis on the traffic signal countdown by conducting a survey of 337 drivers regarding driver attitudes and behaviors on the green signal countdown in Longyan City, Fujian province [15]. The study advised that the countdown signal should be set cautiously. Wu et al. (2009) focused on the driver's decision-making process at countdown signalized intersections [16]. A logistic model was adopted to build the model of behavior decision at countdown signalized intersections based on vehicle types and speed. Zhang et al. conducted a survey on the countdown signal and collected 200 questionnaires from drivers and pedestrians at four intersections in Wanzhuang, Beijing City [17]. The results showed that the drivers and pedestrians sampled had a preference for the countdown signal. Qian and Han preliminarily studied the influence of green signal countdown on traffic safety through a questionnaire investigation of 390 drivers [18]. The finding indicated that the green signal countdown is good for neither traffic safety nor traffic operational efficiency. Thus, the green signal countdown should be used cautiously. Ma et al. conducted a field observation to obtain critical parameters related to drivers and vehicles at two similar intersections, one with GSCDs and the other without GSCD, in Shanghai City, China [19]. They found that GSCD increased the traffic capacity at the sampled intersection and significantly reduced the number of red-light running violations. Qian carried out an eight-question driver behavior survey of 390 drivers regarding the red signal countdown to analyze driver behaviors [20]. Long et al. studied the impact of the countdown timer on driver behaviors after the yellow onset and found that the countdown timer influences drivers stopping or passing through the intersection [21]. Additionally, a correlation exists between the countdown timer and red-light running violations. Huang et al. found that although GSCD stimulates the drivers in dilemma zones to choose to cross the intersection during amber, which produces a higher RLR risk compared with SCD and GSFD, the intersection with GSCD has the lowest RLR violations due to its strong positive effect in cutting down the range of dilemma zones [22]. Li et al. comparatively analyzed drivers' perception-reaction time (PRT) with and without a countdown timer based on the RGB color model and found that the drivers' PRT was decreased from 2.12 s to 1.48 s with countdown signals [23]. Pan et al. attempted to find effects of the end of a green signal countdown on drivers' behaviors when they drive vehicles through intersections based on the data of vehicle position, time, and speed at the entrance of intersections [24]. Fu et al. characterized and modeled driver's brake perception-reaction time (BPRT) to yellow signal at signalized intersections with and without countdown timer and found an increase in driver's BPRT because countdown timer may induce risky driving behaviors [25]. Pan et al. did an interesting study demonstrating that the value of a driver's car has influence on driving behaviors at countdown signalized intersections [26].

As introduced above, three methods are commonly used to study the effects of countdown signals on drivers, including survey, video, and observation in the field. Evaluating the existing studies through questionnaire survey method revealed that the questionnaires are not designed comprehensively enough, because these only involve a part of driving behaviors and do not investigate driving behaviors from the psychological aspect.

3. Method

3.1. Design of Questionnaire. Considering the complexity of driving psychologies and behaviors and the new mode of countdown signal controls, the questionnaire was designed to fully reflect the common and individual characteristics of the driving psychologies and behaviors involving the aspects listed as follows:

(1) Gender: male and female drivers may have significantly different attitudes toward countdown signal controls

(2) Age: age refers to the length of time that one has existed. It is an important indicator to reflect the differences in driving psychologies and behaviors of different age groups

(3) Driving experience: driving experience is used to examine the differences of driving psychologies and behaviors for drivers with different driving experiences

(4) Specific questions associated with driving psychologies and behaviors on the countdown signal controls

3.2. Online Questionnaire Survey. The designed questionnaire was released and conducted by a professional survey website in China. A total of 1051 valid questionnaires were received.

4. Analysis of Survey Results

The survey results were classified and analyzed to indicate the general understanding of drivers and their psychological characteristics, as well as the behavioral characteristics of different types of drivers surveyed.

4.1. Basic Characteristics of Drivers Surveyed. The characteristics of gender, age, and driving experience for the surveyed drivers are shown in Table 1.

Table 1: Characteristics of drivers surveyed.

Questions	Options	Proportion (%)
(1) Gender	(A) Male	62.32
	(B) Female	37.68
(2) Age	(A) Younger than 25 years old	16.94
	(B) 25–30 years old	37.68
	(C) 31–40 years old	22.07
	(D) 41–50 years old	16.46
	(E) 51–60 years old	5.80
	(F) More than 60 years of age	1.05
(3) Driving experience	(A) 0–3 years	36.06
	(B) 4-5 years	26.17
	(C) 6–10 years	20.36
	(D) More than 10 years	17.41

Table 1 shows that the majority of respondents were young drivers and that more male drivers than female drivers responded to the survey. The drivers surveyed below the age of 40 accounted for 76.69%, indicating that young drivers use the Internet more widely in China. For driving age, the drivers with no more than three years of driving experience accounted for 36.06%, which is consistent with the rapid increase of the number of Chinese drivers in the last three years.

4.2. Attitudes and Understanding of Drivers on Countdown Signal Controls. Six questions, questions (4) to (9), were designed to evaluate the attitudes and understanding of drivers on countdown signal controls. The survey data were analyzed, and the results are summarized in Table 2.

Table 2 shows that the majority of the surveyed drivers felt easier driving vehicles on roadway sections than at intersections; they especially felt nervous at unsignalized intersections. Most drivers also supported setting up countdown signal controls, which they considered to be beneficial to driving behavior decisions. Even more drivers thought that countdown signal controls can be conducive to improve traffic safety and traffic operational efficiency. In addition, the proportion of aggressive drivers is not high from the drivers surveyed.

4.3. Attitudes and Understanding of Drivers on Green Countdown Signal Controls. Questions (10)–(15) were designed to investigate driver attitudes on green countdown signal controls and to contrast the behavior of "race against time" at the end of the green light at countdown signal and non-countdown signal control intersections. The analysis results for questions (10)–(13) are shown in Table 3.

According to Table 3, the surveyed drivers who supported the setup of green countdown signals accounted for the majority of respondents. The proportion of drivers who regarded the green countdown signal as having an impact on driving behaviors reaches up to 92.30%. With regard to the display modes of the green countdown, 55.19% of the surveyed drivers selected the partial countdown.

Table 2: Attitudes and understanding of surveyed drivers on countdown signal controls.

Questions	Options	Proportion (%)
(4) Which kind of city road conditions do you find the least stressful? [single choice]	(A) Roadway section	80.21
	(B) Signalized intersection	13.42
	(C) Unsignalized intersection	6.37
(5) What are your attitudes regarding the setting of countdown signal controls at intersections? [single choice]	(A) Support	81.83
	(B) Do not support	12.18
	(C) Does not matter	5.99
(6) If countdown signals are set up at intersections, do you think it will help drivers make behavioral decisions? [single choice]	(A) Helpful	84.87
	(B) Not helpful	11.61
	(C) Does not matter	3.52
(7) Do you think what kind of signal controls more conducive to traffic safety? [single choice]	(A) Countdown signal controls	76.88
	(B) Non-countdown signal controls	23.12
(8) Do you think what kind of signal controls more conducive to traffic operational efficiency? [single choice]	(A) Countdown signal controls	88.39
	(B) Non-countdown signal controls	11.61
(9) You think your own driving behavior tends to [single choice]	(A) Aggressive	15.43
	(B) Conservative	55.90
	(C) Neutral	28.67

Table 3: Attitudes of surveyed drivers on green countdown signal controls.

Questions	Options	Proportion (%)
(10) Do you support setting up a green countdown signal at intersections? [single choice]	(A) Support.	80.02
	(B) Do not support.	17.89
	(C) Does not matter.	2.09
	(D) Others.	0.00
(11) If the green countdown signal control is set up at intersections, what kind of impact will this have on you? [single choice]	(A) Through the countdown signal, I can see the green time decreasing. Thus, I accelerate to pass through the intersection as fast as possible in this phase, thereby increasing my chances of red-light running.	23.98
	(B) Through the countdown signal, I can see the green time decreasing. Thus, I can control vehicle speed better, which reduces my chances of red-light running.	68.32
	(C) Neither the countdown signal nor the non-countdown signal has an impact on me.	6.76
	(D) Others.	0.95
(12) Which of the following control modes of green countdown is better? [single choice]	(A) The countdown from the beginning to the end of the overall period of green light is better.	44.81
	(B) Beginning to show the countdown 30 s before the end of the green light is better.	10.37
	(C) Beginning to show the countdown 20 s before the end of the green light is better.	19.31
	(D) Beginning to show the countdown 10 s before the end of the green light is better.	25.50
(13) When a green light changes to a red light, which transition do you think is more reasonable? [single choice]	(A) Non-countdown green → yellow → red.	13.99
	(B) Countdown green → yellow → red.	47.86
	(C) Non-countdown green → countdown green → yellow → red.	28.83
	(D) Non-countdown green → countdown green → red.	9.32

Table 4: Behaviors of surveyed drivers on the green signal coming to an end in the two cases.

Questions	Options
(14) At countdown signalized intersections, what will you do when you approach the intersection stop line, see the green countdown coming to an end and the yellow light starting at once? [single choice]	(A) Accelerate and pass the stop line before the end of the green countdown or before the end of the yellow light. (B) Decelerate and make sure to stop before the stop line prior to the end of the yellow light. (C) Maintain the original speed; if I cannot stop safely in front of the stop line, then I will pass the stop line before the end of the yellow light. (D) Others.
(15) At non-countdown signalized intersections, when you approach the intersection stop line, see the green light is changing yellow light, how do you do? [single choice]	(A) Accelerate and pass the stop line before the end of the yellow light. (B) Decelerate and make sure to stop before the stop line prior to the end of the yellow light. (C) Maintain the original speed; if I cannot safely stop in front of the stop line, and then pass the stop line before the end of the yellow light. (D) Others.

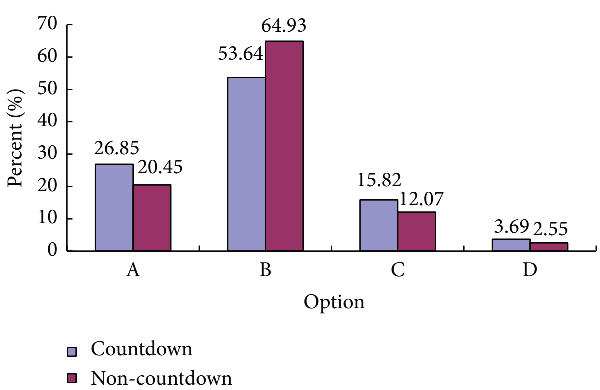

Figure 1: Comparison of driving behaviors before the end of the green light at two types of intersections.

Questions (14)-(15) and their options are described in Table 4, and the comparative analysis is shown in Figure 1.

In comparison with non-countdown signalized intersections (Figure 1), more drivers would like to accelerate passing through intersections while the green light time shifts to the yellow light time at green countdown signalized intersections. However, the difference is not significant. More drivers surveyed agreed with option B at non-countdown signalized intersections than at countdown signalized intersections. The result shows that driving behaviors are more adventurous at countdown signalized intersections than at non-countdown signalized intersections.

4.4. Driver Attitudes and Behaviors on Red Countdown Signal Controls. Questions (16)–(24) were designed to investigate the attitudes and possible driving behaviors of drivers on red countdown signal controls. The analysis results for questions (16)–(19) are shown in Tables 5 and 6. Table 5 summarizes the questions on attitudes and behaviors on red countdown signal controls. Table 6 presents the questions on turning off engines while waiting for the green signal.

Table 5 reveals that most of the drivers surveyed are supportive of red countdown signal controls, and 66.51% of the surveyed drivers considered red countdown signal controls as having an impact on driving behaviors. The proportion of drivers (52.05%) who preferred overall countdowns is close to the proportion of drivers (47.95%) who selected partial countdowns. For question (19), 19.79% of the drivers would accelerate passing through the intersection, which is a very dangerous behavior.

At signalized intersections, the reckless behavior of a driver is largely constrained by other drivers or vehicles. Therefore, the behavior of the first driver in a certain lane is focused on. In Table 6, for question (20), 79.82% of the surveyed drivers would engage the engine gear in advance and accelerate to start once the green light changes. This behavior may cause traffic accidents in conflict directions with vehicles or delayed pedestrians. However, from another angle, it can improve traffic operational efficiency. Regarding question (21), 77.38% of the surveyed drivers who would turn off their engines while waiting would start the engines in advance and then accelerate to move while changing to the green light. For question (22), 58.33% of the drivers surveyed would turn off their engines while waiting when the waiting time is longer than 30 s, which reflects the driver's awareness of conserving energy and reducing exhaust emissions. Question (23) shows that the main causes for not turning off engines at red countdown signalized intersections are feelings of inconvenience and concerns about fuel consumption when restarting the engine. Question (24) indicates that the main causes for not turning off engines are feelings of inconvenience and having no idea of how soon the red light will be over. Note that some questions have a plurality of possible causes or choices; therefore, the percentage sum of multiple-choice questions may be greater than 100%. The calculation principle is the

Table 5: Attitudes and behaviors of surveyed drivers on red countdown signal controls.

Questions	Options	Proportion (%)
(16) Do you support setting up a red countdown signal at intersections? [single choice]	(A) Support.	79.64
	(B) Do not support.	14.65
	(C) Does not matter.	4.85
	(D) Others.	0.86
(17) If red countdown signal controls are set up at intersections, what kind of impact will this have on you? [single choice]	(A) Through the countdown signal, I can know the remaining time of the red light, be ready to drive, and accelerate to pass through the intersection.	36.44
	(B) Through the countdown signal, I know the remaining time of the red light and can decide whether or not to turn off the engine according to the remaining time, thereby reducing fuel consumption.	30.07
	(C) Through the countdown signal, I can know the remaining time of the red light, and thus reduce the anxiety of waiting for a red light.	29.97
	(D) Either countdown or non-countdown has no impact on me.	3.52
(18) Do you think which of the following control modes of red countdown is better? [single choice]	(A) The countdown from the beginning to the end of the overall period of red light is better.	52.05
	(B) Beginning to show the countdown 30 s before the end of the red light is better.	12.94
	(C) Beginning to show the countdown 20 s before the end of the red light is better.	10.47
	(D) Beginning to show the countdown 10 s before the end of the red light is better.	24.55
(19) If you happen to approach an intersection at normal speed and no other vehicles are in front of your vehicle, that is to say, your vehicle is the first vehicle in a certain lane, if you find the red countdown is coming to end, what will you do? [single choice]	(A) Accelerate into the intersection.	19.79
	(B) Decelerate into the intersection.	56.99
	(C) Maintain the original speed and enter the intersection.	21.03
	(D) Others.	2.19

number of times an item is selected divided by the number of drivers surveyed.

4.5. Analysis of Red-Light Running Behaviors and Other Risk Behaviors. Questions (25)–(29) were designed to investigate driving behaviors on red-light running, sudden acceleration, sudden braking, and so on. Question (25) and its options are described in Table 7, and the results are shown in Figure 2.

Question (25) indicates that the proportion of drivers who would intentionally run a red light at countdown signalized intersections is 12.33% (Figure 2). Their main reason for running a red light is to rush through intersections within a very short time, even though the drivers may be well aware of the remaining green light time. In addition, 24.63% of the surveyed drivers revealed good driving behaviors by not running a red light.

Question (26) was designed to correspond to question (25). Its options are described in Table 8, and the results are shown in Figure 3.

Question (26) reflects that cases of red-light running at non-countdown intersections caused by not knowing the time the yellow light will appear and by the sudden transition of yellow light account for a large proportion (63.6%) of the drivers surveyed (Figure 3). Some drivers even attributed their red-light running to the lack of countdown signals. Red-light running that resulted from inattention still accounts for approximately one-third of the total (29.83%).

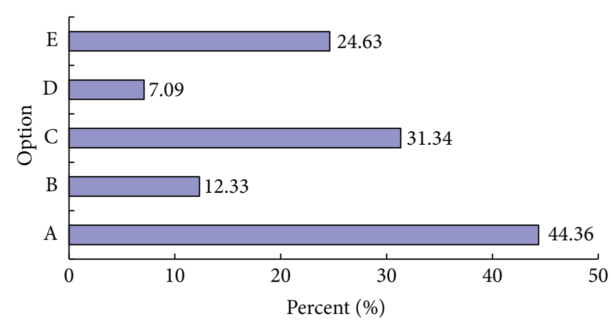

Figure 2: Distribution of reasons for running a red light at countdown signalized intersections.

Question (27) and its options are described in Table 9, and the statistical results are illustrated in Figure 4. Effective countermeasures to reduce red-light running are installing

Table 6: Behaviors on whether engines should be turned off while waiting for the green light.

Questions	Options	Proportion (%)
(20) At countdown signalized intersections, if you do not turn off the engine while waiting, assuming your vehicle is the first vehicle in a certain lane, when you see the red countdown is coming to end, what will you do? [single choice]	(A) Engage the engine gear in advance, and then accelerate to pass through the intersection when the green light begins.	44.62
	(B) Engage the engine gear in advance, slowly glide, and then accelerate to pass through the intersection when the green light begins.	35.20
	(C) Continue to wait until the green light begins, and then engage the engine gear to pass through the intersection.	18.93
	(D) Others.	1.24
(21) At countdown signalized intersections, if you turn off the engine while waiting, assuming your vehicle is the first vehicle in a certain lane, when you see the red countdown is coming to end, what will you do? [single choice]	(A) Start the engine in advance, engage the engine gear beforehand, and then accelerate to pass through the intersection when the green light begins.	46.01
	(B) Start the engine in advance, engage the engine gear beforehand, slowly glide, and then accelerate to pass through the intersection when the green light begins.	31.37
	(C) Start the engine in advance, continue to wait until the green light begins, and then engage the engine gear to pass through the intersection.	20.53
	(D) Continue to wait until the end of the red light, start the engine, and then engage the engine gear to pass through the intersection.	2.09
	(E) Others.	0
(22) At countdown signalized intersections, you will turn off the engine to wait at how many remaining seconds of the red countdown? [single choice]	(A) 30–39 s.	5.33
	(B) 40–49 s.	5.71
	(C) 50–59 s.	6.95
	(D) 60–69 s.	20.36
	(E) >70 s.	19.98
	(F) Never turn off the engine.	41.67
(23) At red countdown signalized intersections, when you meet a red light but do not turn off the engine to wait, what are the causes? (Drivers who will turn off their engines do not need to reply to the question.) [multiple choices]	(A) Turning off and restarting the engine is inconvenient.	65.75
	(B) Turning off and restarting the engine will consume more fuel.	48.72
	(C) Turning off and restarting the engine will increase the wear of the vehicle.	27.69
	(D) Others.	7.33
(24) At non-countdown signalized intersections, when you meet a red light but do not turn off the engine to wait, what are the causes? (Drivers who will turn off their engines do not need to reply to the question.) [multiple choices]	(A) Turning off and restarting the engine is inconvenient.	57.66
	(B) Not knowing how much time of the red light is left.	54.52
	(C) Turning off and restarting the engine will increase the wear of the vehicle.	29.59
	(D) Others.	7.71

Table 7: Reasons for running a red light at countdown signalized intersections.

Questions	Options
(25) At countdown signalized intersections, what are your reasons for running a red light? [multiple choices]	(A) Inattention, not intentionally running a red light.
	(B) In a hurry, intentionally running a red light.
	(C) Intending to pass through the intersection before the end of the green countdown or the end of the yellow light, but runs a red light.
	(D) Others.
	(E) Never runs a red light.

TABLE 8: Reasons for running a red light at non-countdown signalized intersections.

Questions	Options
(26) At non-countdown signalized intersections, what are your reasons for running a red light? [multiple choices]	(A) Inattention, not intentionally running a red light. (B) Not knowing the time that the yellow light will appear, not intentionally running a red light. (C) Transition of the yellow light is too sudden, and I cannot brake to stop before the stop line, not intentionally running a red light. (D) In a hurry, intentionally running a red light. (E) Others. (F) Never runs a red light.

TABLE 9: Measures for reducing the chances of running a red light.

Questions	Options
(27) Which of the following measures do you think can reduce the chances of running a red light? [multiple choices]	(A) Install automatic facilities to capture the behavior of red-light running (e.g., electronic police, camera, etc.). (B) Install countdown signal lights. (C) Strengthen education on traffic safety, and raise awareness on traffic safety. (D) Others.

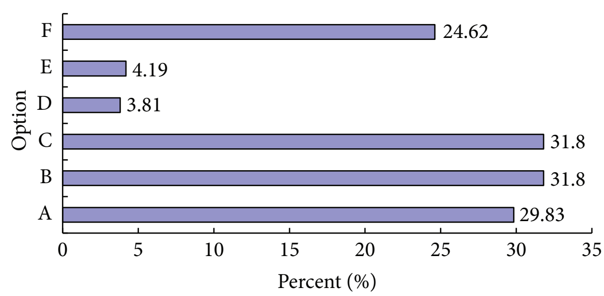

FIGURE 3: Distribution of reasons for running a red light at non-countdown signalized intersections.

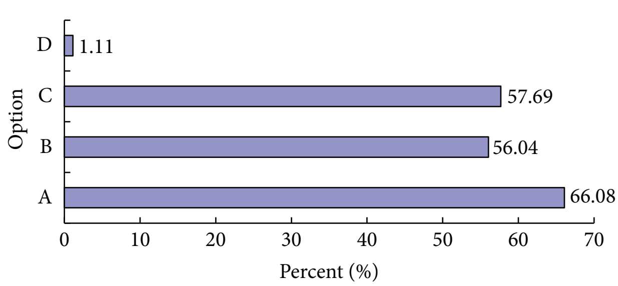

FIGURE 4: Distribution of measures to reduce the chances of running a red light.

automatic-capture facilities, enhancing education, and setting up countdown signal lights based on the degree of influence.

Questions (28)-(29) and their statistical results are shown in Table 10. The proportion of acceleration at the end of the green light at countdown signalized intersections is 26.07% more than that at non-countdown signalized intersections. The key factor is the existence of the countdown signal. For sudden braking, the possibility of occurrence at non-countdown signalized intersections is higher than that at countdown signalized intersections. Regardless of whether a driver is at countdown signalized intersections or at non-countdown signalized intersections, sudden braking will increase while the yellow light starts.

4.6. Attitudes and Understanding of Drivers on Display Modes of Countdown Signals. Questions (30)–(32) were designed to investigate the attitudes of drivers on the display modes of countdown signals. The statistical results are shown in Table 11.

According to Table 11, most of the surveyed drivers selected the mode of countdown display with overall lights (red, green, and yellow). Nearly half of the surveyed drivers considered the red countdown light to be beneficial in improving traffic operational efficiency.

4.7. Cross-Analysis of Typical Questions. The psychological and behavioral characteristics of drivers are closely related to the driver's gender, age, and driving experience. The cross-analysis between gender and attitudes toward countdown signals is carried out based on questions (1) and (7) of the survey data. The analysis results shown in Table 12 indicate that the majority of male and female drivers supported the setting up of countdown signal controls, and male drivers are more inclined to support countdown signal controls.

The cross-analysis between gender and behaviors before the end of the green countdown is conducted based on questions (1) and (14), as listed in Table 10. Table 13 shows that the proportions of male and female drivers are very close in decelerating to stop by the end of the green countdown. Compared with the male drivers, the surveyed female drivers were also more likely to accelerate passing through the stop line by the end of the green countdown or by the end of

Table 10: Risky driving behaviors at different intersections.

Questions	Options	Proportion (%)
(28) What kind of signal controls make you inclined to accelerate to pass through an intersection? [single choice]	(A) Countdown signal control, the green countdown is coming to an end.	61.75
	(B) Non-countdown signal control, the green light is flashing.	35.68
	(C) Others.	2.57
(29) What kind of signal controls that make you incline to urgently decelerate? [single choice]	(A) Countdown signal control, the green countdown is coming to an end.	19.31
	(B) Countdown signal control, the yellow countdown begins to counting.	27.40
	(C) Non-countdown signal control, the green light is flashing.	21.50
	(D) Non-countdown signal control, the yellow light is starting.	30.73
	(E) Others.	1.05

Table 11: Attitudes and understanding of surveyed drivers on the display modes of countdown signals.

Questions	Options	Proportion (%)
(30) Do you think it is reasonable to show only the red countdown, but not the yellow and green countdowns? [single choice]	(A) Reasonable.	23.69
	(B) Unreasonable.	65.37
	(C) Does not matter.	10.94
(31) If you answered "Reasonable" in question (30), what are the reasons? [multiple choice]	(A) It is not easy to lead to red-light running at the end of the green light.	85.82
	(B) It allows the drivers waiting for the red light to be prepared to start in advance, which is conducive to traffic operational efficiency.	47.76
	(C) Others.	5.33
(32) If you answered "Unreasonable" in question (30), what are the reasons? [multiple choice]	(A) It is easy to lead to red-light running at the end of the green light.	67.46
	(B) It allows the drivers waiting for the red light to be prepared to start in advance, which may result in a traffic accident, especially with no vehicle waiting for the red light in a certain lane.	46.81
	(C) Others.	3.62

Table 12: Cross-analysis between gender and attitudes toward countdown signals.

X	*Y*				
	(A) Support	(B) Do not support	(C) Does not matter	(D) Others	Total
(A) Male	87.75%	6.84%	0.85%	4.56%	100%
(B) Female	76.12%	16.42%	3.48%	3.98%	100%

Table 13: Cross-analysis between gender and behaviors before the end of the green countdown.

X	*Y*				
	(A) Accelerate and pass the stop line before the end of the green countdown or before the end of the yellow light	(B) Decelerate and make sure to stop before the stop line before the end of the yellow light	(C) Maintain the original speed; if I cannot safely stop in front of the stop line, then pass stop line before the end of the yellow light	(D) Others	Total
(A) Male	18.23%	62.96%	14.25%	4.56%	100%
(B) Female	20.40%	61.69%	10.95%	6.97%	100%

the yellow light, indicating that female drivers may not be conservative about the behavior in question.

The cross-analysis between gender and behaviors while the green light is turning into the yellow light at non-countdown intersections is conducted based on questions (1) and (15), as shown in Table 14. According to the results, at non-countdown intersections, for the option "accelerate and pass the stop line before the end of the yellow light," male drivers are more aggressive than female drivers. In comparison with question (14), the female drivers surveyed were more

Table 14: Cross-analysis between gender and behavior before the end of the green light at non-countdown signalized intersections.

X	Y				
	(A) Accelerate and pass the stop line before the end of the yellow light	(B) Decelerate and make sure to stop before the stop line before the end of the yellow light	(C) Maintain the original speed; if I cannot safely stop in front of the stop line, then pass the stop line before the end of the yellow light	(D) Others	Total
(A) Male	19.09%	67.24%	10.83%	2.85%	100%
(B) Female	4.98%	75.62%	13.93%	5.47%	100%

conservative in the condition of uncertain remaining time than male drivers.

5. Conclusion and Discussion

According to the analysis results of the survey, several conclusions can be drawn. (1) Most of the surveyed drivers preferred countdown signalized intersections and tended to select the mode of countdown display of overall lights (red, green, and yellow). (2) Most of the drivers considered countdown signal controls as capable of improving not only traffic safety but also traffic operational efficiency, which is consistent with the findings from earlier studies [17, 19] but is contrary to the studies in [18, 20]. (3) Regardless of whether green countdown or red countdown controls are set up, most of the drivers considered countdown signal controls as having an impact on driving psychologies and behaviors. However, the impact may not be conducive to improve traffic safety. (4) The proportion of drivers intentionally running red lights is relatively small at countdown signalized intersections or non-countdown signalized intersections. However, the time by the end of the green signal and at the onset of the yellow signal is the key time of red-light running at both types of intersections. According to the survey results, the installation of an automatic-capture system to catch traffic violations is conducive to reduce the occurrence of red-light running. (5) Female drivers are traditionally viewed as having more conservative driving behaviors compared with male drivers. However, the analysis results indicate that the driving behaviors of female drivers surveyed are not conservative under clear green countdown conditions. Nevertheless, female drivers are very conservative under non-countdown conditions, which confirms the general psychological characteristics indicating that males are more adventurous than females under unknown conditions.

Driving psychologies and behaviors are complex phenomena. To further study the effects of countdown signals on driving psychologies and behaviors, several ways may be recommended: (1) using professional equipment to collect indicator parameters of driving psychologies and behaviors at countdown and non-countdown signalized intersections with actual traffic conditions and then analyzing the data; (2) at countdown signalized or non-countdown signalized intersections, observing or photographing driving behaviors and then analyzing the behaviors; and (3) using a more scientific comparison and analysis of data obtained by different methods to draw reasonable conclusions.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] F. Pan, L. Zhang, J. Lu, Q. Xiang, and L. Lu, "Application of access management techniques in safety improvement at highway intersections," *Journal of Beijing University of Technology*, vol. 37, no. 2, pp. 237–242, 2011.

[2] F. Pan, L. Zhang, J. Lu, J. J. Zhao, and F. Wang, "A method for determining the number of traffic conflict points between vehicles at major-minor highway intersections," *Traffic Injury Prevention*, vol. 14, no. 4, pp. 424–433, 2013.

[3] Standardization Technical Committee on Transportation in Ministry of Public Security of China, *Road Traffic Counting Down Display Unit (GA508-2004)*, The Ministry of Public Security of the People's Republic of China, 2004.

[4] Standardization Administration of China, *Specification for Setting and Installation of Road Traffic Signals (GB14886-2006)*, Standards Press of China, Beijing, China, 2006.

[5] Standardization Administration of China, *Road Traffic Signal Lamps (GB14887-2011)*, Standards Press of China, 2011.

[6] Y. Wang, "Why not adopt the red light countdown devices at the signalized intersections in Shanghai city," *Traffic and Transportation*, vol. 2, no. 17, 1999.

[7] K. M. Lum and H. Halim, "A before-and-after study on green signal countdown device installation," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 9, no. 1, pp. 29–41, 2006.

[8] M. R. Ibrahim, M. R. Karim, and F. A. Kidwai, "The effect of digital count-down display on signalized junction performance," *American Journal of Applied Sciences*, vol. 5, no. 5, pp. 479–482, 2008.

[9] T. Limanond, S. Chookerd, and N. Roubtonglang, “Effects of countdown timers on queue discharge characteristics of through movement at a signalized intersection,” *Transportation Research Part C: Emerging Technologies*, vol. 17, no. 6, pp. 662–671, 2009.

[10] Y.-C. Chiou and C.-H. Chang, “Driver responses to green and red vehicular signal countdown displays: safety and efficiency aspects,” *Accident Analysis and Prevention*, vol. 42, no. 4, pp. 1057–1065, 2010.

[11] A. Sharma, L. Vanajakshi, V. Girish, and M. S. Harshitha, “Impact of signal timing information on safety and efficiency of signalized intersections,” *Journal of Transportation Engineering*, vol. 138, no. 4, pp. 467–478, 2012.

[12] P. Papaioannou and I. Politis, “Preliminary impact analysis of countdown signal timer installations at two intersections in Greece,” *Procedia Engineering*, vol. 84, pp. 634–647, 2014.

[13] J. Devalla, S. Biswas, and I. Ghosh, “The effect of countdown timer on the approach speed at signalised intersections,” *Procedia Computer Science*, vol. 52, pp. 920–925, 2015.

[14] M. R. Islam, D. S. Hurwitz, and K. L. Macuga, “Improved driver responses at intersections with red signal countdown timers,” *Transportation Research Part C: Emerging Technologies*, vol. 63, pp. 207–221, 2016.

[15] Y. Wang and X. Yang, “Discussion on setting traffic signals with counting down display unit at intersection based on traffic safety,” *China Safety Science Journal*, vol. 16, no. 3, pp. 55–70, 2006.

[16] W.-J. Wu, Z.-C. Juan, and H.-F. Jia, “Drivers’ behavioral decision-making at signalized intersection with countdown display unit,” *Systems Engineering—Theory and Practice*, vol. 29, no. 7, pp. 160–165, 2009.

[17] J. Zhang, Y. He, X. Sun, and X. Liu, “Effects of countdown signal at urban intersection on driving behaviors,” *Journal of Transport Information and Safety*, vol. 27, no. 5, pp. 99–101, 2009.

[18] H. Qian and H. Han, “Influence of countdown of green signal on traffic safety at crossing,” *China Safety Science Journal*, vol. 20, no. 3, pp. 9–13, 2010.

[19] W. Ma, Y. Liu, and X. Yang, “Investigating the impacts of green signal countdown devices: empirical approach and case study in China,” *Journal of Transportation Engineering*, vol. 136, no. 11, pp. 1049–1055, 2010.

[20] H. Qian, “Influence of red signal countdown on traffic safety and efficiency,” *Journal of Transport Information and Safety*, vol. 29, pp. 65–68, 2011.

[21] K. Long, L. D. Han, and Q. Yang, “Effects of countdown timers on driver behavior after the yellow onset at Chinese intersections,” *Traffic Injury Prevention*, vol. 12, no. 5, pp. 538–544, 2011.

[22] H. Huang, D. Wang, L. Zheng, and X. Li, “Evaluating time-reminder strategies before amber: common signal, green flashing and green countdown,” *Accident Analysis and Prevention*, vol. 71, pp. 248–260, 2014.

[23] Z. Li, J. Zhang, J. Rong, J. Ma, and Z. Guo, “Measurement and comparative analysis of driver’s perception–reaction time to green phase at the intersections with and without a countdown timer,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 22, pp. 50–62, 2014.

[24] F. Pan, D. Yun, L. Zhang, Y. Ma, Y. Meng, and H. Tang, “Analysis and modeling of behavior of catching green signal at countdown signalized intersections,” *China Safety Science Journal*, vol. 25, no. 7, pp. 147–152, 2015.

[25] C. Fu, Y. Zhang, Y. Bie, and L. Hu, “Comparative analysis of driver’s brake perception-reaction time at signalized intersections with and without countdown timer using parametric duration models,” *Accident Analysis and Prevention*, vol. 95, pp. 448–460, 2016.

[26] F.-Q. Pan, L.-X. Zhang, T. Liu, G.-X. Kang, M. Li, and F.-Y. Wang, “Modeling of driving behaviors at countdown signalized intersections considering the value of car,” *Journal of Transportation Systems Engineering and Information Technology*, vol. 16, no. 2, pp. 64–69, 2016.