

Evaluating the Effects of Countdown Timers on Intersection Safety: A Case Study in Arak, Iran

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Abstract:

Roadway Intersections are known as safety bottlenecks in urban traffic networks. According to the national traffic accident fatality statistics of Iran, 27% of all fatal accidents happened in urban areas in 2017. This rate is as low as 8% for provinces with very low population density and as high as 74% for the Tehran province, which is the most populated province of the country. Many measures have been taken to increase intersection safety. But lately, it has been illustrated that some of them may even reduce safety in some case. Countdown devices as one of these measures have been evaluated in this study. Aside with increasing intersection efficiency, one other purpose of using Green Signal Countdown Devices (GSCD) and Red Signal Countdown Devices (RSCD) is to increase intersection safety by giving drivers information about the remaining time of each signal phase. four scenarios were designed and separately implemented at one intersection of Arak urban network, Iran. Data was collected by reviewing videos recorded by a traffic control camera located at the intersection and totally 1888 cycles have been investigated. This study demonstrated that it is necessary to evaluate each countdown timer when operating alone, as well as in combination state. A T-test analysis has been applied and the results show that GSCD has a positive effect on intersection safety indicators, most effectively when RSCD is disabled. Statistical analyses indicate that the “best scenario” caused enhancement of total safety indicators compared to the average of other three scenarios for about 10%.

Keywords:

Intersection Safety, Safety performance indicators, Countdown Timers, GSCD, RSCD

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1. Introduction

Due to high rates of injuries and fatalities at and around intersection facilities, it is important to enhance their safety. One of the measures to enhance intersection safety was installing the countdown timers. Green Signal Countdown Devices (GSCD) and Red Signal Countdown Devices (RSCD) are used to show the remaining time in seconds of the “green” and “red” phases respectively for approaching traffic. Installation of these devices were intended to help drivers in decision making process for crossing the intersection or stopping before the stop line while the signal is in the transitional state from green toward red or from red to green. Despite many studies that investigated the impacts of these devices from different aspects, the effect of them on intersection efficiency and safety is not conclusive and has become a controversial matter. In this study, the effect of countdown timers on intersections safety will be investigated, using different scenarios.

Literature Review

Below are the major aspects of intersection countdown timer's effects that were investigated by many researchers.

Driver behavior: Drivers' behavior is one of the most important factors in traffic safety. Understanding of this issue and its effective factors can be helpful to reduce the influences of human factors on traffic accidents [1]. Being aware of remaining time of each signal phase can affect drivers' behaviors. The effect of countdown timers on driver behavior during the yellow interval has been examined in Long's study and it was found that there is strong correlation between the presence of countdown timers and an increase in red-light violations [2]. In Li's study about driver Perception Reaction Time (PRT) with and without countdown devices, it was declared that countdown timers decrease drivers' PRT.[3]. Driver's Brake Perception Reaction Time (BPRT) was also investigated in Fu's study for both situations, with and without a countdown timer. But according to their study, unlike reference [3] findings, the mean BPRT with countdown timer was found significantly longer than that without a countdown timer [4]. A car following

model has been established in Tang's study to investigate the effect of traffic signals on driver's behavior. A model was finally presented which could enhance the intersection safety status and reduces the mean vehicle fuel consumption during the intersection crossing period [5]. According to the findings of Pan's study which is executed by a questionnaire, drivers consider the countdown timer as an effective device for increasing the safety and operational efficiency of the intersections [6].

Intersection safety: One of the reasons of widespread use of countdown timers at signalized intersections is the safety perception, as it was investigated by some researchers. Drivers' responses towards Green Signal Countdown Devices (GSCD) and Red Signal Countdown Devices (RSCD) have been studied separately in Chiou's study. Data has been collected on a date before installing the countdown devices and three other dates with time intervals of 1.5 months after installing them. The study shows that in an intersection with GSCD, stopping before the stop line during the last seconds of green phase is more probable, but generally these devices cause deviation in driver decisions and have negative effect on intersection safety [7]. The effect of GSCD on approaching vehicular speed has been studied in India. Two different signalized intersections have been studied, one of them is equipped with countdown timer display and another one is not. As an overall result, it has been declared that GSCD encourages drivers to travel with higher speed and also, presence of GSCD is found to be relevant with fewer red-light violations [8]. A systematic review on effects of countdown timers on intersection safety has been done in Fu's study. Some of the safety performance indicators that have been considered in that study are: crossing the intersection after yellow onset, red-light violation and rear-end crash possibilities. One of the findings of this study is that GSCD has contributed to decrease red-light violations and rear-end crash possibility. RSCD has also shown to decrease the red-light violation in short term, but its effect has vanished over the time [9]. A simulated environment has been used in Islam's study to investigate the effect of GSCD on intersection safety. One of the findings of this study is that GSCD increases the possibility of "stop" decision for vehicles caught in dilemma zone [10]. In Liu's study, two types of traffic light assistance systems are compared, one of which is time-based and another speed based. It is said that both assistance systems are

effective but time-based ones have a better performance. According to the findings of the study, GSCD increases the risk of yellow cross and red-light violation but also enhances the intersection efficiency and comfort [11]. The effect of countdown timers on the red-light violation is considered in Sobata's study. One of the results of this study is that the use of countdown timers does not contribute to reduce the level of safety [12]. In Bao's study, driver choices have been investigated at 3 intersections, one of them equipped with GSCD and the other two equipped with Green Signal Flashing Device (GSFD). It has been said that the driver cross/stop choice is widely related to vehicle's spot speed, distance to the stop line, the signal heads and monitoring devices. According to the findings of the study, drivers are more likely to stop before the stop line during the yellow phase in GSCD intersections than the ones in GSFD intersections [13].

Intersection efficiency: Many studies have investigated the operational enhancements at intersections after countdown timer installations. Six intersections, three with countdown timers and three without them have been investigated in Ibrahim's study. It is suggested that countdown timers have negligible effect on initial delay but the effect on headway is significant and it decreases the discharge headway for subsequent vehicles in the queue [14]. Also in Limanond's study, it is found that GSCD increases saturation headway and therefore it decreases saturated flow rate and intersection capacity [15]. Chiou and Chang have declared that RSCD enhances intersection efficiency and it is claimed that RSCD is less controversial and more beneficial than GSCD [7]. It has also been declared in Fu's investigation that RSCD increases the intersection capacity and has a positive effect on its operational efficiency [9].

Pedestrian countdown timers: The effect of pedestrian countdown timers has been investigated both for the pedestrians and the drivers crossing the intersection. Such studies evaluated the effect of pedestrian countdown timers on decreasing crashes, motorcyclist red-light violations and pedestrian crossing behaviors [16-18].

As the literature review of present study indicates, the driving culture of the studied region, intersection conditions, data collection strategies, analysis methodologies and different safety performance measures in each study, affect the consistency of result comparisons and evaluations

One important item to consider is that in all of these previous studies, either the individual operation of one countdown device (GSCD or RSCD) or activation/deactivation of both GSCD and RSCD at the same time has been investigated and in none of these studies, the effect of simultaneous and distinct operation of GSCD and RSCD were not studied and compared. The aim of this study is to have a more precise assessment over this issue by designing and implementing four scenarios of countdown timer displays, which helps to evaluate the effect of each countdown timer (RSCD or GSCD) on intersection safety, with and without the operation of the other one.

2. Methodology

2-1- Designing & Executing Scenarios

In order to investigate the effects of countdown timers on intersection safety and comparing their performance when operating together or individually, four scenarios have been designed and separately executed. These scenarios are defined as follows:

Scenario 1: Both RSCD and GSCD are enabled.

Scenario 2: Both RSCD and GSCD are disabled.

Scenario 3: RSCD is enabled and GSCD is disabled.

Scenario 4: GSCD is enabled and RSCD is disabled.

As mentioned before, the scenarios are designed in a way that the effect of each countdown device on intersection safety can be evaluated with or without operation of the other one.

All defined scenarios have been executed at one intersection (Helal-Ahmar) on Beheshti Street, Arak, Iran. Figure 1, illustrates the location of the intersection and its surrounding. The west bound direction has two through lanes and one dedicated right turn lane. Only through movements have been considered for this study. The intersection is controlled by a pre-timed signal controller with 120 seconds cycles and 65 seconds of green phase for the eastbound/westbound direction, operating under scenario 1 as default mode. The countdown timers (GSCD and RSCD) have been in operation at this intersection and many other crossings in the city for more than a year and the city drivers are generally familiar with countdown timer display technology.

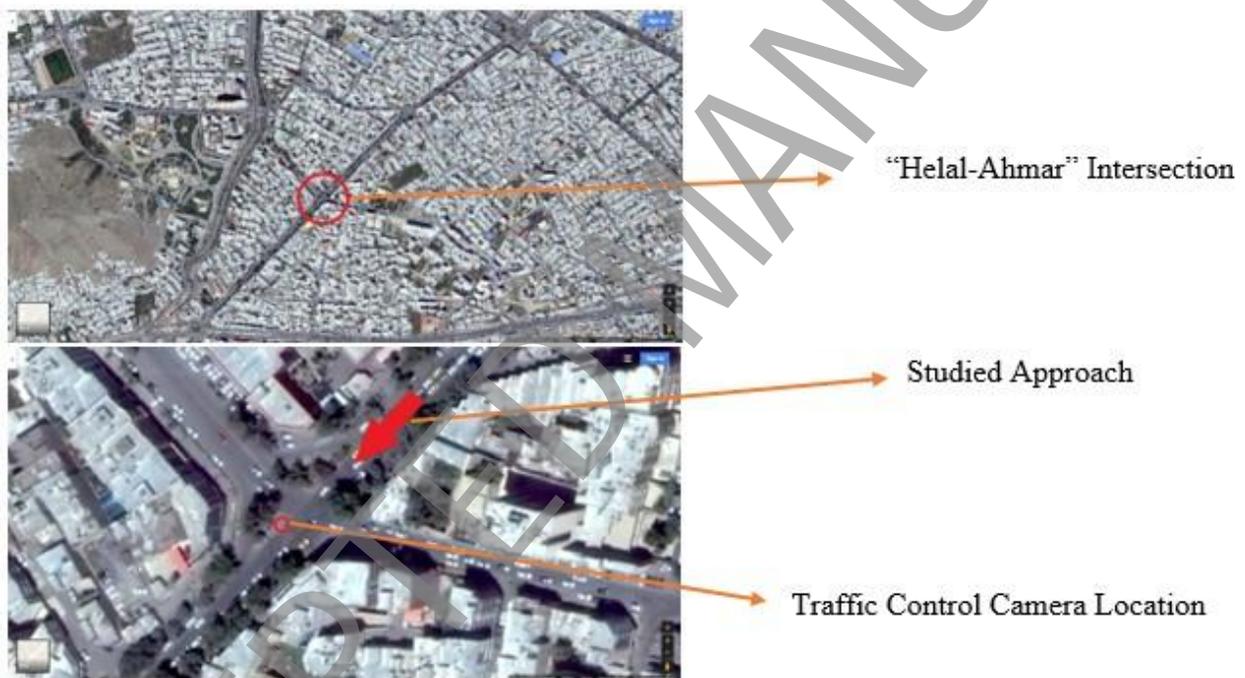


Figure 1: Location of Helal-Ahmar intersection

2-2- Data

Data needed for this study was derived from watching the videos captured by traffic control camera located at the intersection (Figure 1) and recording the operational behavior and patterns at each cycle. The scenarios have been executed in May of 2017, with the assistance of Traffic Control Department of Arak Municipality, Iran. Figure 2 illustrates the traffic control camera position and signal countdown timer operation during the execution period of scenario 4. Due to limited resources and experiment permission period restrictions by the city, each scenario has been executed for a week, and two successive weekdays were selected to be studied from each execution week. Video recordings were analyzed for each selected weekday and both morning and evening intervals, 4 hours each. a total number of 1,888 cycles were surveyed in this study (Table 1).



Figure 2: Traffic control camera position and signal countdown timer operation under scenario 4

Table 1: Number of Cycles Studied in Each Scenario

Scenario Number	Number of Studied Cycles
1	460
2	475
3	477
4	476
total	1888

As the purpose of this paper is to identify parameters that might affect intersection safety and efficiency, major safety performance indicators (for both pedestrians and drivers) have been investigated and described below which are aligned to the indicators that have been mentioned in other studies [7, 9, 19]:

Yellow cross: When a vehicle crosses the intersection right after the onset of yellow phase. This behavior is dangerous because it happens mostly by speeding and therefore increases the crash possibility.

Red cross: When a vehicle crosses the intersection after the onset of red phase. It is explicit that this behavior will intensely increase crash possibility.

Stop after stop line: This is directly related to the pedestrian safety. When a vehicle stops after the stop line and violates the pedestrian crosswalk area, it increases the pedestrian-vehicle collision possibility.

Early start: This happens when a driver, waiting in red-light queue, starts to move his/her vehicle at the last seconds of red phase but before its termination. This is a dangerous behavior because there is a possibility of colliding with vehicles moving on the opposite phase which may be travelling at a higher speed to cross the intersection before their green phase terminates.

The main focus of the present study is on the number of cycles each indicator has occurred in, and the number of indicator occurrences in each cycle has not been considered. Each indicator occurrence in four scenarios are compared two by two based on the one-sample T-test statistics and are discussed below.

3. Results and Discussion

Figure 3 shows the indicators' occurrence differences between four scenarios during all studied time periods (morning and evening intervals, aggregated) of two weekdays of scenario weeks. The indicator occurrences have been presented by the ratio of the total number of cycles that each indicator has occurred in, to the total number of investigated cycles in each scenario (as presented in Table 2).

Table 2: number and percentage of cycles with occurrence of each indicator in each scenario

scenarios	total studied cycles	number and percentage of cycles with ...			
		yellow cross	red cross	stop after stop line	early start
1	460	163	66	198	315
		35.43%	14.35%	43.04%	68.48%
2	475	191	78	216	175
		40.21%	16.42%	45.47%	36.84%
3	477	224	67	213	280
		46.96%	14.05%	44.65%	58.70%
4	476	164	23	183	179
		34.45%	4.83%	38.45%	37.61%

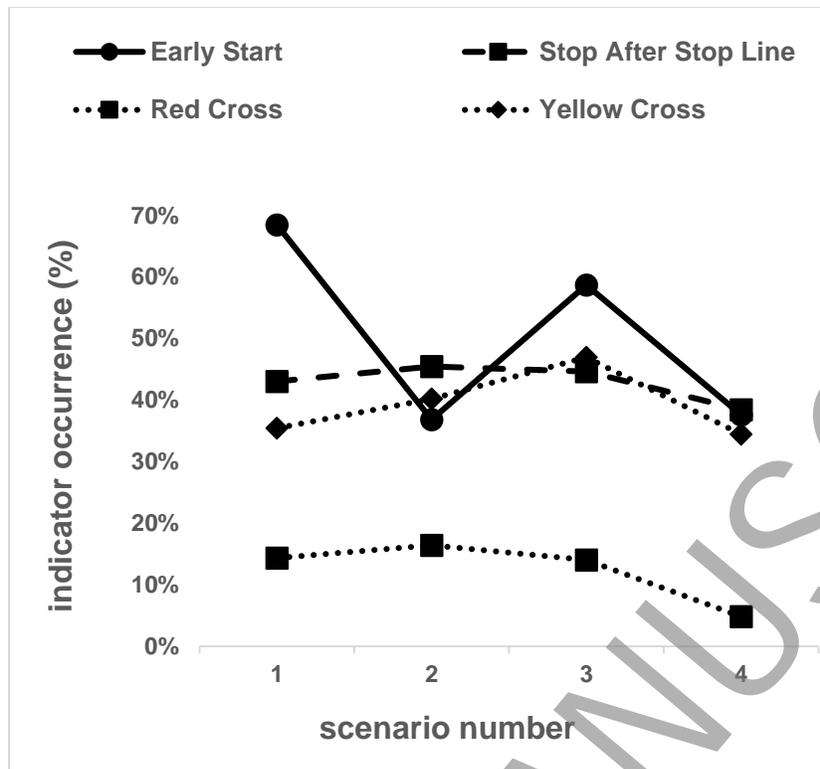


Figure 3: The occurrence ratio of each safety performance indicator in each scenario

To find out the significance of differences in each indicator occurrence between each two scenarios, a one-sample T-test statistical analysis has been performed. Table 3 shows the results of T-test statistical analysis. According to the results, difference in “stop after stop line” occurrence between scenarios 3 and 4 has Sig. value of 0.052. Also “yellow cross” occurrence between scenarios 2 and 4 has the Sig. value of 0.067. These differences would not be considered significant in a confidence interval of 95%, but their Sig. values are so close to the critical value of 0.05. So the confidence interval is chosen to be 90% in order to obtain more homogenous results. The bold numbers in Table 3 show the differences which can be assumed to be significant by a confidence interval of 90%.

Table 3: Comparison of Scenarios in All Study Time Periods (Morning and Evening), Using T-test

scenarios compared	yellow cross		red cross		stop after stop line		early start	
	t	sig.	t	sig.	t	sig.	t	sig.
1 and 2	1.506	0.132	0.877	0.38	0.747	0.455	-10.204	0
1 and 3	3.606	0	-0.132	0.895	0.496	0.62	-3.124	0.002
1 and 4	-0.314	0.753	-4.984	0	-1.431	0.153	-9.942	0
2 and 3	2.103	0.036	-1.019	0.308	-0.254	0.8	6.911	0
2 and 4	-1.836	0.067	-5.896	0	-2.199	0.028	0.243	0.808
3 and 4	-3.957	0	-4.922	0	-1.946	0.052	-6.66	0

The following results can be derived from diagrams and T-test results of this study:

- The only significant difference between scenarios 1 and 2 is about the “early start” indicator. It shows that evaluating the simultaneous effect of GSCD and RSCD is not sufficient to obtain a precise assessment of the effect that countdown devices have on intersection safety, and it is necessary to study the effect of these devices individually, as well.

“Yellow cross” has occurred significantly less in scenario 4 than scenarios 2 and 3. It shows that drivers who know the remaining time of green phase, mostly decide to stop when the phase is ending and it reduces “yellow cross” occurrence, which is expected to increase intersection safety.

The most “yellow cross” occurrence is in scenario 3, in which the GSCD is disabled. Also, between scenarios 1 and 2, “yellow cross” occurrence in scenario 2, in which both countdown timers are disabled, is more than scenario 1 and it also declares the positive effect of GSCD on decreasing the occurrence of this indicator, which is expected to increase the intersection safety.

- “Red cross” occurrence in scenario 4 is significantly less than all other scenarios. One of the possible reasons of this, can be found in Fu and Zou findings about the influence of pedestrian countdown devices on crossing behavior of pedestrians [18]. According to their study, knowing the time remained of

red signal can cause pedestrians to violate the red phase if it is going to last long. It seems that it might be possible to extend this finding for vehicle drivers as well. So, not knowing the time remained of red phase can reduce the red-light violation caused by its long period, which is clearly happening in scenario 4.

- “Stop after stop line” threatens pedestrian safety. This safety performance indicator has also occurred significantly less in scenario 4 than scenarios 2 and 3. It means that when drivers have enough knowledge of remaining green phase time, they could and would perform safer. When the green light suddenly turns into yellow, without any act of informing drivers, stopping safely before the stop line would be difficult for them.
- Differences of “early start” occurrence between all scenarios is significant and meaningful except between scenarios 2 and 4. Regarding the diagrams, a result that can be obtained is that disabling RSCD helps to reduce “early start” occurrence and it also can be assumed that GSCD status has no effect on occurrence of this safety performance indicator, because the only difference of scenarios 2 and 4 is based on GSCD status but there is no significant difference in “early start” occurrence in these two scenarios.

According to the findings of previous studies, some researchers believed that countdown timers and especially GSCD reduced the occurrence of “yellow cross” indicator [7, 10, 13], some other researchers said that GSCD reduces the occurrence of RLV as well [8, 9, 12, 15, 20]. One of the findings of Chiou’s study is that RSCD has no long-term effect on increasing the intersection safety [7], and Devalla deduced that GSCD has no especial effect on startup lost time and it can be assumed that it has no effect on “early start” either [8]. All of the findings of these studies correspond with the findings of present study. But on the other hand, there are some studies that their results contradict the current presented results. Some researchers have claimed that GSCD increases the occurrence of “yellow cross” or has no effect on reducing it [2, 9, 13, 16, 20]. Some others believed that countdown timers, especially GSCD increase the occurrence of RLV [2, 13, 14], and Chiou found that RSCD has a positive effect on reducing the occurrence of “early start” [7]. Although it has been said that this effect disappears after several months from RSCD installation

date. These disparities may be caused because of different driving cultures, data collection and data analysis.

4. Conclusions and Suggestions

This study evaluates the effects of countdown timers on intersection safety. Most of intersections, either have no countdown timer or have both Red Signal Countdown Display (RSCD) and Green Signal Countdown Display (GSCD), operating simultaneously. It seems that these usual countdown display methods are not helpful for intersection safety. In this study, individual operation of each countdown timer has also been considered. Four practical scenarios by different type of countdown timer displays have been designed and separately executed at one intersection and the data was collected from videos recorded by a traffic control camera which was installed at the intersection. These four scenarios are: Scenario 1: Both RSCD and GSCD are enabled, Scenario 2: Both RSCD and GSCD are disabled, Scenario 3: RSCD is enabled and GSCD is disabled, Scenario 4: GSCD is enabled and RSCD is disabled.

By investigating the individual operation of each countdown timer, it is found that RSCD causes increase in “early start” of vehicles waiting at a red-light, which is not helpful for intersection safety and can increase the possibility of crashes with vehicles crossing the intersection in the last seconds of their green phase. Also, GSCD has shown to have a positive effect on most of safety performance indicators reviewed in this study such as reducing “yellow cross”, “red cross” and “stop after stop line”. The findings of this study indicated that the scenario 4, in which GSCD is operating while RSCD is disabled is the most effective scenario of countdown timer display for having a safer intersection operation. Statistical analyses indicate that scenario 4 caused enhancement of total safety indicators compared to the average of other three scenarios for about 10%. When RSCD is disabled, there are fewer early starts in red phase, so even if drivers in opposite phase, tend to accelerate during the last seconds of green phase and at the beginning of yellow phase (which also has occurred less in GSCD individually operating situation), the possibility of collision

is low, because vehicles waiting at a red signal are not aware of remaining time and tend not to enter the intersection before their green signal phase.

Several limitations of this work are worth discussing. First, the traffic control camera was installed in a place where made it visible for drivers and it could affect their behavior. Better results could be derived if the camera was hidden from the driver's sight. The second limitation of the study is that only one approach of the intersection is investigated. For future studies it would be better if the camera gets located in a place where all approaches of the intersection could be observed. As the last point, it could be seen in previous studies that despite the negative effect of RSCD on intersection safety, this countdown timer has a positive effect on intersection efficient operation [7, 9, 15]. One other suggestion for future investigations is to obtain a new scenario in which the benefits of RSCD on intersection efficiency could also be used, as the negative effects of it on safety are lowered.

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