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A before-and-after Study on Traffic Signal Countdown Control Device

By

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Abstract:

Capacity of signalized intersections is the key parameter in operating and performing traffic in urban roadways network. Recently, several countdown timer traffic signals have been installed at intersections in many Egyptian cities. The main function of these timers is to provide drivers with the remaining time of the current indicator (e.g. red and green) until the onset of the next interval time.

This paper reports a before and after study which evaluates the difference in driver response along an approach of a signalized intersection installed with a traffic signal countdown device. Accordingly, two main objectives are stated for this study the first one is to investigate the effect of the red indicator countdown device on start-up delay time of queued vehicles, the second objective is to investigate the effect of the green indicator countdown device on the number of drivers who violate the red time.

The required data for this study was collected at an approach of a signalized intersection in Shebin El-Kom city by using video recording technique. The data was collected before and after installing the countdown device at this intersection using video tap recording.

The findings provided an answer for the question of that to what extent do the countdown timer devices improve the response of the driver at traffic signals? It was found that the countdown traffic signals significantly affect the driver's behavior and reduce the start-up delay. The findings also indicated that there was no significance difference in the number of red-running violations after the installation of the countdown timers.

Keywords:

Signalized Intersection, Capacity, Countdown timer, Startup delay, and Violations

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1. Introduction:

Surface intersections are considered as bottleneck points in the urban roadway network, since a number of traffic streams are conflict. Several types of control strategies can be applied at intersections in order to eliminate the conflict points. The type of control method is mainly defined based on the traffic volumes and the intersections geometry. Among these control strategies, the traffic signals are the most widely used over the world for controlling traffic at surface intersections. However, at high traffic volumes, queues of vehicles form downstream of the traffic signal and a significant amount of delays are observed. Delay time at signalized intersection is one of the most important parameters that directly affect the capacity of signalized intersection.

Increasing the capacity of intersections is the key factor for improving performance and quality of service of traffic movements over the whole urban roads network. Three approaches can be treated in order to increase the capacity of signalized intersection; optimizing traffic signal timing and phasing, maximizing saturation flow rate during the green period, and minimizing total delay time. The majority of the previous studies treated the intersection capacity from the first two approaches. On the other hand, minimizing total delay time did not have the same attention from traffic engineering researchers.

Another important aspect, in this study, is the violation of drivers at start of the red indicator of the signalized intersections. Red light violation represents a significant safety issue for communities.

Recently, several countdown timers had been installed at intersections in Shebin El-Kom city and some other cities in Egypt. These timers could stimulate stopped drivers in the head of the queues, in the case of red interval, to start moving promptly on time when the green indicator turns on. This advance information is supposed to help drivers in reducing their start-up delay and consequently improve capacity and level of service. On the other hand, green countdown timer help drivers near the stop line of the intersection to make informed stopping/crossing decision during the critical phase-change from green to red, since, at the end of green indicator, many drivers may miss the estimation of the remaining time to the red, even in case of yellow indicators, and then they violate the red indicators.

In this research two approaches of one signalized intersection were used to study the effect of countdown timer on driver behavior and intersection approach capacity as well as red light violations. The data is collected at the same intersection before and after the installation of the countdown signal.

2. Literature Review:

1) Delay time at signalized intersection

Highway Capacity Manual (HCM-2000) [1], the most widely use guideline for analysis signalized intersections, classified the delay times occur at such intersections into three types; uniform delay, incremental delay, and initial queue delay. The uniform delay is the delay time assuming uniform arrivals, stable flow, and no initial queue. It is based on the first term of Webster's delay formulation and is widely accepted as an accurate depiction of delay for the idealized case of uniform arrivals [2]. The incremental delay occurs due to non-uniform arrivals and temporary cycle failures (random delay) as well as delay caused by sustained periods of over-saturation (over-saturation delay). It is sensitive to the degree of saturation of the lane group, the duration of the analysis period, the capacity of the lane group, and the type of signal control. The initial queue delay occurs when a residual queue from a previous time period then additional delay is experienced by vehicles arriving in the period since the initial queue must first clear the intersection.

2) Startup delay

Startup delay is important because it affects the saturation flow rate and the capacity of roadway lanes at downstream traffic signals. Startup delay is associated with human reaction time in conjunction with motorists' desires to allow the gaps between successive stopped vehicles to widen beyond what is acceptable while stopped. It is well established that vehicles in motion allow larger gaps between vehicles as speed increases. If two successive vehicles started simultaneously to accelerate at the same rate, the distance between them at the end of acceleration would be the same as while stopped in the queue. Such gaps would be much too short when in motion [3].

Startup delay was tackled in the previous researched in terms of the Saturation Flow Rate (SFR). The headway time is the main parameter in these studies, since the SFR can be calculated as:

$$SFR = 3600/h \tag{1}$$

Where; h is the average headway time of the queued vehicle with excluding the headways of the first four vehicles in order to eliminate the impact of the startup delay.

The previous studies reported that the first few queued vehicles involved in the start up delay and the delay value can be calculated as follows:

$$dn = \tau + n \times T \tag{2}$$

where;

dn = startup delay for the nth vehicle in a queue (sec),

τ = excess startup time of the lead vehicle in a queue (sec),

n = ordinal position of a specific vehicle in a queue (n = 1, 2, 3, ...), and

T = uniform or average startup lag time of each driver in a queue (sec).

Headway times for the first few vehicles tend to vary by their position in a queue [4]. The driver of the first vehicle in the queue must observe the signal change from red to green and react to this change by taking his/her foot off the brake, and accelerate through the intersection. Within the queue the first headway will normally be the longest as a result of this process. The second vehicle in the queue follows a similar process, except that the reaction and acceleration period can partially occur while the first vehicle begins to move. The second vehicle will be moving faster than the first as it crosses the reference line, because it has an additional vehicle length in which to accelerate. Its headway will be generally less than that of the first vehicle. The third and fourth vehicles will each achieve a slightly lower headway than the preceding vehicle. After a certain number of vehicles, "n", the effect of the start-up reaction and acceleration has dissipated as shown in Figure (1). It shows that the startup delay takes place at the first 6 vehicles.

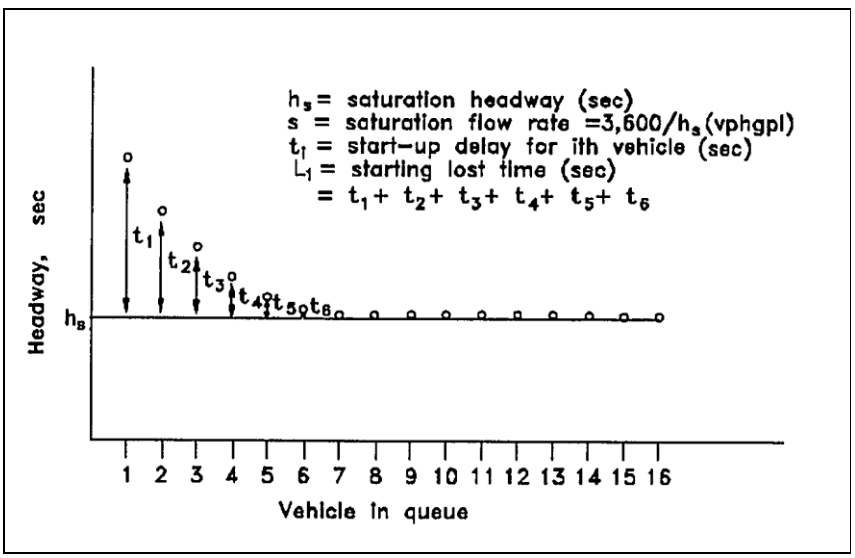


Figure (1): *Saturated Headway Time and Starting Lost Time [4].*

A comparative study was made between Yokohama city in Japan and Dhaka city in Bangladesh in terms of headway values of the passenger cars at signalized intersections [5]. Figure (2) illustrates the value of headway against the vehicle position in the queue. It shows the headway value decreases with increasing the position number of the vehicle in the queue.

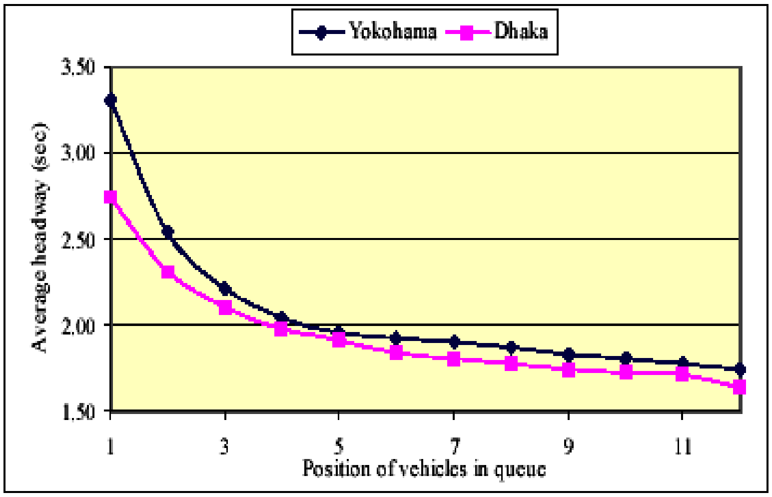


Figure (2): *Comparison of Headway values in Dhaka and Yokohama in terms of Vehicle Position.*

A recent study of the same topic was conducted by Jin et al. 2009 [6]. Detailed distribution of the departure headways was carefully examined by using video traffic data collected from Beijing between 2006 and 2007. The results show that the departure headways for each position follow a certain log-normal distribution. The statistical results of the observed headways are summarized in Table (1), which shows that both the mean and variance of the observed headways decrease with increasing a vehicle's position number in the queue.

The only study that tackled the impact of the countdown traffic signal on the intersection capacity was conducted by Kidwai et. al. (2005), the data was collected at the same intersection in JKR, Malaysia before and after the installation of the countdown signal. The clearance time of the queued vehicle was observed. Then the throughput (capacity) of the approach was calculated. The analysis showed that countdown timer has got very little effect on capacity [7].

Finally, the HCM-2000 listed that the startup delay takes place at the first 4 vehicles. Based on the studies listed above, the most vehicles that influenced by the startup delay is the first four vehicles in the queue. Thus, this study will investigate the impact of the countdown traffic signals on the throughput flow for the first four queued vehicles.

Table (1): *Statistics of Departure Headways (in seconds) as Observed at Beijing Intersections*

Position	Sample size	Maximum	Minimum	Range	Mean	Median	Standard division
1	423	9.74	1.26	8.48	4.53	4.26	1.51
2	423	8.36	1.05	7.31	3.05	2.81	1.08
3	423	6.69	1.05	5.64	2.76	2.56	0.93
4	422	9.32	1.05	8.27	2.57	2.39	0.90
5	416	7.77	1.05	6.72	2.51	2.35	0.88
6	394	6.26	1.05	5.21	2.36	2.23	0.78
7	298	4.91	1.05	3.86	2.19	2.10	0.69
8	146	5.25	1.05	4.16	2.04	1.89	0.66
9	42	3.15	1.05	2.10	1.87	1.83	0.56

3) Violations at Signalized Intersections

Drivers approaching a signalized intersection during the end of green/onset of amber must decide whether to stop or to enter and clear the intersection. This decision can be difficult if they are trapped in the dilemma zone, due to certain combinations of speed and distance from the stop line, in which the driver will be neither able to clear the signals nor to be able to stop in time. A rear end accident may occur when two successive drivers make conflicting decisions at the end of green signal, as the lead driver decides to stop while the following one wishes to enter the intersection. On the other hand, inappropriate actions such as red light running/violation may result in a right angle accident with conflicting paths.

Using violations as a measure of effectiveness is still a measure that agencies can easily and quickly measure and is a measure which is easily understood by decision makers.

Studies showed that occupant injuries occurred in 45% of red light running crashes as compared to all other urban intersection crashes [8].

In a study by Federal Highway Administration (FHWA) [9], Red light running crashes account for 16-20% of total crashes at urban signalized intersections. Red light running can be particularly dangerous since many red light running crashes are right-angle collisions [10].

A number of methods can be implemented to alleviate the complexities of decision-making during such critical change period situation. One of these methods could be using countdown timer traffic devices. Such devices provide advance information to drivers on the remaining time to red signal. This countdown timing would, in turn, help drivers to make informed decisions on stopping/crossing the intersections.

Recently two studies have been implemented to study the impact of countdown timers on red light violations. In both studies, the findings indicated that there was a substantial decrease in the numbers of red-running violations in case of the installation of countdown timers and the reduction was generally significant.
In the first study by Kidwai et al. [7] using data from Malaysia, It was found that there is an average of 66.2% red light running in the intersections using conventional signals whilst that of the intersections using count-down signals the red light running is 37.1%. The red light running is computed based on the relevant cycles when there are vehicles approaching the intersection during the change over phase.

The methodology adopted for the second study, by Lun and Halim [11] in Singapore, focused on a before-and-after study. The study compared the red light running occurrences before countdown timers installation with those obtained at various months after countdown timers started operation, that is, namely at 1.5-month, 4.5-month and 7.5-month.

The findings indicated that there was a substantial drop in the occurrences of red running violations at 1.5-month after the installation of the countdown timers and the reduction was generally significant at 95% confidence level. On the whole, an average reduction of about 65% was achieved at 1.5-month. However, this was not the case over the longer term as the impact of countdown timers appeared to be dissipated over time as the red light violation numbers had gone back to almost the before installation of countdown timers. The authors added that countdown timer traffic signals remained to be somewhat effective under low traffic volumes and not effective at all under high traffic volumes in the longer term. The authors asked for further countdown studies focused at other intersections with different signal settings.

One of the main objectives of this paper is to study the impact of the countdown traffic signals on the red light violations.

3.Data collection and site selection

The required data for this study was collected at two approaches of a three leg signalized intersection in Shebin El-Kom city, Egypt. Each one of the approaches is consisted of three lanes; two for through movements and one for turning movement. This study considered only the through movements of the two approaches. The data was collected using video tap recording technique. The recording was conducted before and after installing the countdown device in order to absolutely study the effect of countdown timers, keeping other factors the same. Recordings were carried out in each case, with and without timer, in each approach, for about five hours in a normally working day, during daylight hours. During almost all data collection periods, the weather was clear and the pavement was dry. Figure (3) shows pictorial view of the traffic signal before and after installing the countdown timer.

Figure (3): *Pictorial view of the traffic signal before and after installing the countdown timer at the same approach.*

4. Startup Delay Analysis:

4.1. Data Extraction Methodology

As discussed before in the literature review section, the previous studies proved that the startup delay takes place at the first four queued vehicles. Accordingly, the analysis of the startup delay in this study is carried out based on the observed departure times of the first four vehicles stopped at the investigated approaches of the signalized intersection.

For accuracy, the accumulative value of headway time of the four vehicles is used in the analysis process. This accumulative headway time is the elapsed time from the onset of the green light until the moment when the front bumper of the fourth queued vehicle crosses the stop line. This methodology decreases the error in measuring the accumulative headway time by using stop-watch, since one measure is taken for each cycle of the traffic signal instead of measuring four headway times for the individual departure of the first four vehicles. This means that the number of the measured accumulative time equals the number of valid cycles of the traffic signal.

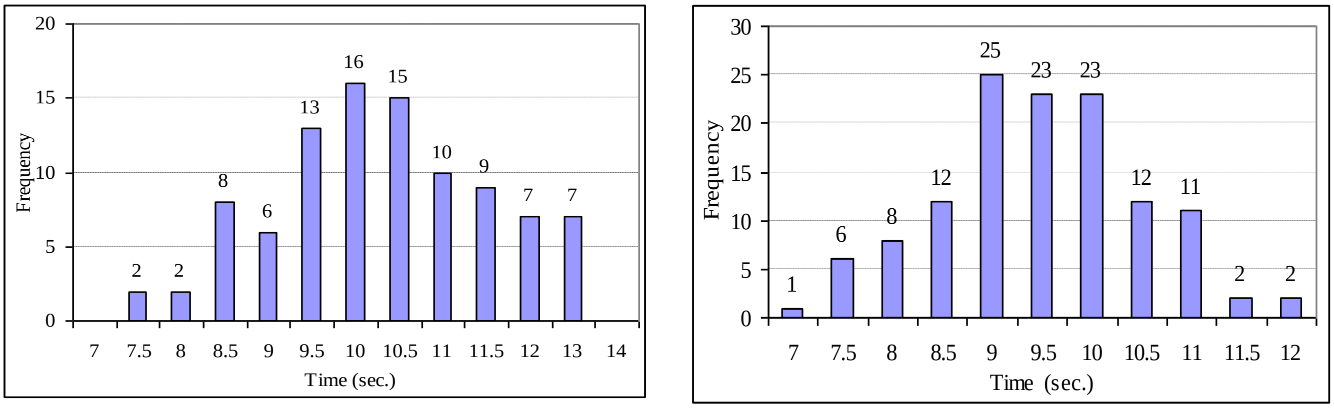
To avoid the impact of heavy vehicles, the cycles that contain one or more heavy vehicles in the first four queued vehicles were eliminated. In addition, headway times that observed in case of disturbance by illegal pedestrian crossing were also omitted. Furthermore, the through traffic only was taken into consideration in this study in order to avoid the impact of turning movements (i.e., right and left turns). During the recording period a number of 166 cycles of the traffic signal is observed. A number of 95 cycles were observed in case of "without" installation of the countdown device and a number of 125 cycles were observed in case of "without" installation of the countdown device. The cycle length is 90 seconds with 42 second green light and 45 red light periods. Since two approaches were investigated, the total observations should be 332 (166 ×2) cumulative headway times. Among these observations a number of 219 observations were found valid based on the above conditions in the both approaches (i.e., 65.9 % valid observations).

4.2.Analysis Process

The accumulative headway times of the first four queued vehicles during the valid cycles are measured at each lane of the two investigated approaches for through traffic streams. The data was extracted in case of "with" and "without" installation of the countdown traffic signal device. Number of the observed accumulative headway times in case of "with" countdown device is 95 observations and in case of "without" countdown device are 125 observations. Figure (4) shows the frequency distribution of the observed headway times in both cases.

The statistical software package SPSS is used to analysis the observed headway times. Table (2) shows the summary of the main features of the observations in case of "with" and "without" countdown device. This table shows that the mean value of the observed cumulative headway time is 10.09 seconds in case of "without" countdown device with standard deviation value of 1.29 seconds. The mean value of the observed cumulative headway time in case of "with" countdown device is 9.24 seconds with standard deviation value of 1.01 seconds. These results reveal that the cumulative headway time is a little lower in the case of "with" countdown device than in the case of "without" device about 9.2% reduction. In addition, the dispersion of the observed time is high in case of "without" countdown device compared to "with" countdown device.

Lower headway time means higher capacity (flow rate is the inverse of the average value of headway time). The raised question now is that to what extent the capacity improved by using the countdown device. Thus, a statistical comparison between the observed distribution of the headway times in both cases, "with" and "without" countdown devices, is conducted using SPSS software package. Figure (5) shows the cumulative distribution of the observed headway times in both cases. It seems that these two distributions are different. The statistical test "compare means of independent-samples T test" is carried out to investigate the difference between the two distributions. The results of the statistical test are shown in Table (3). The results mean that there is a statistical difference between the mean values of both cases at a level of significant of 5%



a) in case of "Without" Countdown device

b) in case of "Without" Countdown device

. **Figure (4):** *Frequency of the observed cumulative headway times*

Table (2): *Main features of the observed cumulative headway times*

Signal Type	N	Mean	Std. Deviation	Std. Error Mean
Without With	95 125	10.09 9.24	1.296 1.008	0.133 0.092

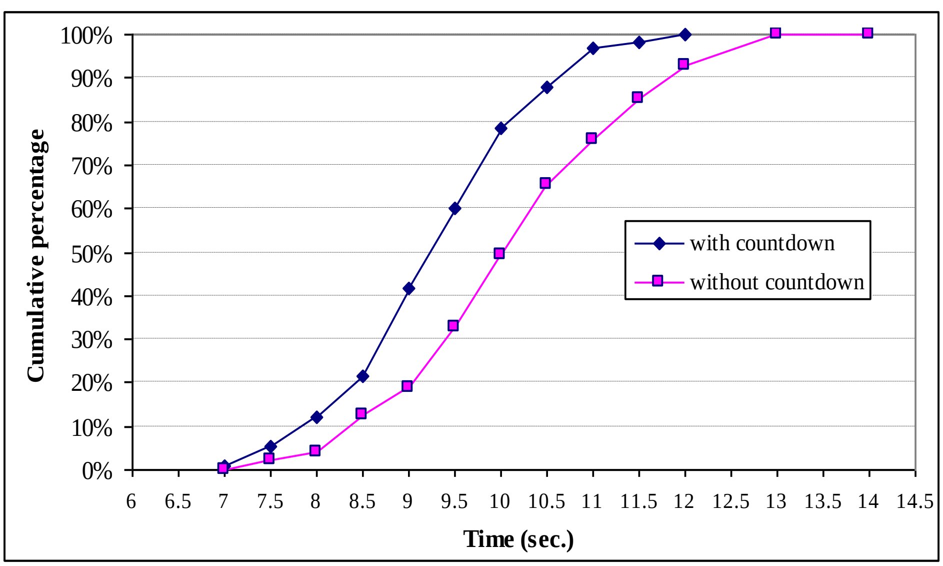


Figure (5): *Cumulative distribution of the observed cumulative headway time in the both cases*

Table (3): *Result of the independent-samples T test*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	5.142	.024	5.512	218	.000	.85635	.15536	.55016	1.16255
	Equal variances not assumed			5.329	172.653	.000	.85635	.16069	.53919	1.17352

4.3. <u>The impact on the Approach Capacity</u>

The observed reduction of 9.2% in the observed cumulative headway times by using countdown device does not mean that the capacity of the intersection approach increases by the same value. Since this reduction takes place for the first four vehicles only, it is no longer applied over all the queued vehicles during the green period. To explore the impact of the countdown devices on the approach capacity, it is assumed that the countdown devices affect the behavior of the first four drivers only. In other words, the departure headway times during the remaining period of the green time (i.e., after departure of the fourth vehicle until the end of the green light period) is assumed to be the same in the both cases.

$$percentage\,change\,in\,apprach\,capacity = \frac{Averagede\,departure\,of\,\,first\,\,four\,\,vehicles \times percentage\,observed\,\,change}{Total\,\,green\,time}$$

By applying this equation in our case,

$$Percentage\,change\,in\,apprach\,capacity = \frac{10.01 \times 9.2}{42} = 2.2\,\%$$

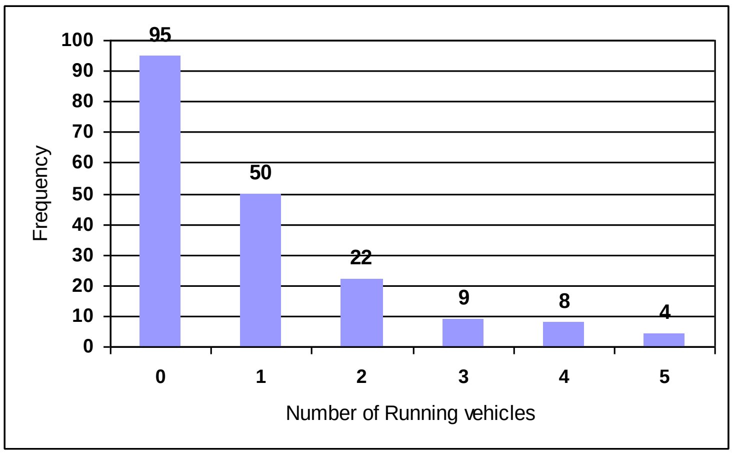
It seems that there is a very limited increase in the capacity of the signalized intersection due to the installation of traffic countdown timers. This result may refer to the driver behavior as well as to the location of the countdown signal. In terms of capacity, the countdown signal should be clearly seen for the first stopped vehicle in the queue. Accordingly, it is highly recommended to install a countdown signal downstream of the intersection approaches.

<u>5. Red Light Violation Analysis:</u>

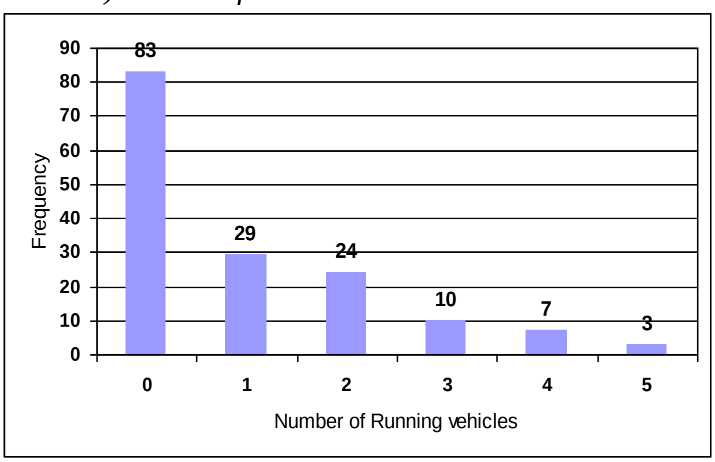
A red-running/violation event is defined as any occurrence in which the front of a crossing vehicle passes over the stop line of a signalized intersection after the onset of the red signal indication.

The effectiveness of the digital countdown signals in red light violations can be evaluated in two ways. Reduction in total accidents or specific accident types (i.e. rear end, right angle) as digital countdown could be a safety treatment. However, it is difficult to evaluate the impact of such device in the short term since accident analysis usually require several years of accident and traffic data after the treatment is installed. As a result, the effectiveness of digital countdown signals on red light running can also be evaluated using differences in the number of red light running violations before and after device installation.

A total number of 348 (160 in the case of with and 188 in the case of without) valid red light intervals from the two through approaches were used for the red light violation analysis. Intervals with any disturbance from pedestrian crossings that observed during the onset of the red light were omitted from the analysis. Figure (6) shows the distributions of these data according to number of running vehicles per each red interval. This distribution could be a typical distribution for signalized intersection red light violations.



a) in case of "Without" Countdown device



b) in case of "With" Countdown device

Figure (6): *Frequency of the observed Red Light Violations*

The statistical software package SPSS is used to analysis the observed red light violations. Table (4) shows the summary of the main features of such observations in case of "with" and "without" countdown device.

Table (4): *Main features of the observed red light violations*

Signal Type	N	Mean	Std. Deviation	Std. Error Mean
Without	188	0.92	1.24	0.091
With	160	0.99	1.28	0.102

This table shows that the mean value of the observed number of vehicle red light violations is 0.92vehicle/cycle in the case of "without" countdown device with a standard deviation of 1.24. The mean value of the observed number of vehicle red light violations is 0.99vehicle/cycle with a standard deviation value of 1.28. Even though the mean values, in Table 3, unexpectedly indicate that the red light violations in the case of "with" are slightly higher than that in the case of "without", this was verified using appropriate statistical tests.

From Figure 6, the distributions of the red light running vehicles are seriously different from normal distribution. In such cases, the nonparametric tests for comparing means should be used instead of parametric tests (i.e. T-tests) [12].The Mann-Whitney test is an alternative to the independent samples in this case. Most nonparametric methods use statistics, such as the median, that are resistant to outliers and skewness. The results of the Mann-Whitney test are presented in Tables 5 and 6.

Table (5): *The table of ranks for the Mann-Whitney test*

Case	N	Mean Rank	Sum of Ranks
With	160	176.27	28203.50
Without	188	172.99	32522.50
Total	348		

Table (6): *The output of the Mann-Whitney test*

	Case
Mann-Whitney U	14756.500
Wilcoxon W	32522.500
Z	-0.329
Asymp. Sig. (2-tailed)	0.743

In the process of determining the value of the statistic U, in the Mann-Whitney test, all the records in the dataset are ranked in order of magnitude, after which the means of the ranks of the records in each of the two cases are calculated. In Table 5 the mean rank of the records obtained under the "with" case is higher than that of the records obtained under "without" case. However this difference is insufficient for the test to achieve significance.

From Table 6, the Asymp. Sig. value of 0.743 indicates that there is no significance difference between the two cases. This means that the installation of the countdown timers does not have impact on the number of red light violations. This results disagree with those of the two other previous studies in other countries [7,11]. This could depend significantly on the driving behavior in the specific country under study. This could be also due to varying driver attitudes and habits, lifestyles and level of motoring law enforcement inter alia. Even though it is recommended to study the impact of countdown timers on red-light violations using more sites in Egypt.

6. Conclusions:

This paper is mainly aimed to investigate the impact of installing the countdown device at signalized intersections on the driver behavior. A before and after study on driver behavior was conducted at a signalized intersection in Shebin El-Kom city. The two main objectives for this study are to investigate the effect of the red indicator countdown device on start-up delay time of queued vehicles, and to investigate the effect of the green indicator countdown device on the number of drivers who violate the red time.

The investigated parameter in the first objective is the cumulative headway time of the first queued vehicle, i.e., the elapsed time from the onset of the green light until the front bumper of the fourth queued vehicle crosses the stop line. The main findings of the analysis process for the first objective can be summarized as follows:

- The distribution of the observed cumulative headway time of the first four queued vehicles is statistically different in both cases, "with and "without" countdown, at a significant level of 5%;
- The startup delay of the first four queued vehicle is reduced by about 9.2% in case of "with" countdown device;
- Based on the assumption that the driver behavior of the fourth vehicle is not changed in both cases, "with" and "without" countdown, the capacity increases by about 2.2% by installing countdown device. This seems to be a very limited advantage in terms of capacity.

For second objective of this paper, the results found that the installation of the countdown timers does not have any significant impact on the number of red light violations. This result disagrees with those of the studies in other countries. The reasons could be due varying driver attitudes and habits in Egypt to that in other countries. Nevertheless, it is recommended to study the impact of countdown timers on red-light violations using more sites in Egypt.

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