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Drivers' Behavior at Signalized Intersections Operating with Flashing Green: Comparative Study

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Abstract
In Jordan, thirty-four signalized intersections out of 105 within Greater Amman Municipality were tested to operate with the flashing green change interval without prior justification or establishing guidelines for such practice. This research attempts to assess the impact of the used practice on driving behavior conducting a comparative study between two sets of signalized intersections. The first set of signalized intersections operates with flashing green and the second set of signalized intersections operates without flashing green.
Results showed that average approach speed of vehicles crossing intersections that operate with flashing green change interval is higher than the average approach speed for vehicles crossing intersections which operate without flashing green. The proportion of vehicles crossing intersections during flashing green change interval is significantly higher than the proportion of vehicles crossing the intersections during change interval at intersections that operate without flashing green. While the proportion of vehicles jumps before green on intersections operating with flashing green light is lower than the proportion of vehicles jumps before green on intersections operating without flashing green. Guidelines should be developed to control such application. Future research will expand the sample size to cover wide spectrum of intersections allover Jordan, and will consider the crash history records at each studied intersection.
Keywords: Traffic control; flashing green signals; driving behavior

1. Introduction

Traffic control systems are provided to insure safe operation and discharge traffic in orderly sequence to resolve conflicts between vehicles. Traffic signals operate by assigning the right of way successively to intersection approaches. The red, yellow, or green light that is displayed to drivers in a given movement gives visual indication for right of way assignment. Therefore, to insure the efficiency of the traffic control system; the traffic control signals must be performed considering safety, operational performance, and driver understanding measures; by conveying a clear and simple meaning in a timely manner.

Signalized intersections with high approaching speed need to have safe and effective warning, control, and intersection geometric treatments. In Jordan, thirty-four signalized intersections out of 105 within Greater Amman Municipality (GAM) were tested to operate with the flashing green change interval without prior justification or establishing guidelines for such practice. The 34 signalized intersections did not have common characteristics in terms of geometry and traffic conditions, and therefore, this research attempts to assess the impact of the used practice on driving behavior; this research was conducted as a comparative study between two sets of signalized intersections. The first set of signalized intersections operates with flashing green and the second set of signalized intersections operates without flashing green.

The research goal was established to investigate how do drivers respond to change interval at signalized intersections that operate with flashing green? Are they behaving differently compared to signalized intersections that do not operate with flashing green? Two aspects were considered to answer the research question: approaching speed and drivers' compliance to the red traffic signals (proportions of drivers crossing on red.)

Traffic engineering researchers investigated the impacts of using different techniques at the end of green interval to provide additional information that would help users to make better decisions. Users at signalized intersections behave differently during signal transition interval. Many researchers investigated drivers' behavior; others investigated pedestrians' behavior, while some researchers investigated the interaction between motorized and non-motorized users. The researchers investigated the behavior under different operating techniques (countdown; flashing green; advanced warning signs; etc.). Some researches approached the topic from a safety perspective;

others looked into the efficiency aspect.

LI and WANG (2010) analyzed the effect of common traffic signal control designs on safety and efficiency in light of traffic regulations and made suggestions on the designs of traffic signal timing and countdown devices, and on the current traffic safety regulations and other relevant traffic laws based on theoretical and practical applications in the field. Lin and Cheng (2013) related the phenomenon of yellow-light runners to dilemma zones suggesting to adopt engineering countermeasures to reduce unintentional yellow-light running by either adjusting the approaching speed, adaptive signaling, or advance warning signs.

Köll, Bader, and Axhausen (2004) investigated the drivers' stopping behavior at signalized intersections programmed with and without flashing green before amber. Results showed that "the flashing green increases the numbers of early stops, as drivers tend to underestimate the duration of the time to the end of amber." Speed and distance to stop line, and their interaction were found to explain the stopping process. Nikolaos and Athanasios (2009) investigated the behavior of users in street crossings with flashing green beacon. Authors concluded that flashing beacons helped both pedestrians and drivers to be more aware of the presence of other road users in their way.

Dong, Fu, and Sun (2011) studied the non-motorized vehicle drivers' behavior with flashing green and green countdown devices at intersections in a comparative study of stop/pass decision process. The study findings indicated that "the earlier stop/pass decisions to be made with green countdown had a greater impact on conservative non-motorized drivers than flashing green." The study concluded that "the risk probability at the intersection with green countdown is bigger, but the severity of accidents with flashing green is larger."

Another study by Dou et al. (2013) evaluated the impacts of flashing green before amber on drivers' stop/cross decisions at signalized intersections in China using an empirical approach to better understand the safety effects of flashing green before amber on signalized intersections in China. Researchers found that "flashing green installation serves only to encourage stopping but does not curb red light violations." This finding agrees with a previous study (Lum and Halim, 2006) which reported drivers' response along an approach of a signalized intersection before and after installing a green countdown device (GSCD). Results showed that "red-running violations were significantly reduced by about 65% at 1.5-month after-GSCD but its effectiveness tended to dissipate over time as the violation numbers had bounced back to almost the before-GSCD level." Authors concluded that the longer term performance of GSCD would only help to encourage stopping but not decreasing red-violations.

Limanond, Chookerd, and Roubtonglang, (2009) approached the use of countdown timers to investigate the queue discharge characteristics of through movement at signalized intersections. Authors found that the countdown timers had a significant impact on the start-up lost time, while the countdown timers do not have much impact on the saturation flow rate of signalized intersections. Hong-bo, and Sheng, (2009) investigated the influence of intersection transition signal on traffic safety. Authors concluded that it is not wise to prohibit users from entering the intersection during amber interval and recommended to cancel the green signal countdown while keeping the countdown for red signal.

Long,Han,and Yang, (2011) investigated the effects of countdown timers on driver behavior after the yellow onset at Chinese intersections. The results suggested that countdown timers can positively influence driver behaviors to decide whether to stop or cross the intersection. Yang (2012) studied the complexity of drivers behavior and traffic flow characteristics at intersections in China. It was found that the presence of countdown timers may encourage yellow running behavior and late entry into intersections.

Sharma, et al. (2011) studied the impact of signal timing information on both safety and efficiency of signalized intersections in India. Although, authors acknowledged that driving behavior and traffic heterogeneity in India is different, results showed that for different types of vehicles in the presence and absence of information (timers for each signal interval) enhances efficiency. Authors emphasized on the trade-off between safety and efficiency and the choices drivers make in the presence/absence of such information. McIntyre, et al. (2012) simulated the human factors of dilemma zone warning systems where participants in the three advanced warning conditions received one of two types of roadside flashing warnings or an in-vehicle warning in advance of the end of green, while the control group received no advance warning. Results provide little evidence of unsafe responses associated with the advance warnings, such as increasing speed.

2. Research Methodology

In order to achieve the research goal, observational field study was conducted at six signalized intersections (half operating with flashing green; and the other half operating without flashing green). The six intersections were selected randomly from different regions within GAM. The two sets were comparable where each intersection in the first set is coupled with another intersection in the second set. The two coupled intersections were approximately operationally identical to each other. The following factors were considered for coupling: traffic characteristics and approaching speed, intersection shape and geometrics. The first two couples were (T) intersections, while the third couple was right angle cross (four leg) intersection.

The collected data can be grouped into geometric data (approaching grade, number of lanes, and lanes width); traffic data (15-minute time interval during peak periods; traffic composition; number of vehicles cross on green, red, yellow "flashing green", or jumps before green, and approaching speed); traffic control data (operation type, signal timing, and signal phasing.)

A typical 8-mm video camera was used to record part of above data. The fifteen percentiles, averages, and eighty-fifth percentiles of speeds at each intersection were estimated using the data for at least 82 vehicles in free flow conditions. Speeds were measured at the regular spacing from the traffic light at each intersection: (0 m, 20 m, 40 m, and 60 m), which are determined by using of 30 meters rubber tape. The speed values are determined by running the recorded video on a TV and attempting to determine the time (in seconds) for each vehicle to cross the interested spacing using a stopwatch. Then, speeds were calculated using distance and time. The data of average approach speed, 15^{th} and 85^{th} percentiles of approach speed, posted speed and percentages of crossed and stopped vehicles were reported.

The researcher acknowledges many limitations faced this research. For example, the sample size was calculated for 95 % confidence level to make inferences about the data within ± 5 % error. Therefore, for each of the six intersections the minimum number of observations was maintained (385 vehicles should be observed). Also, since there are no available data before applying the flashing green, the two sets of signalized intersections were assumed to be comparable to each others, but they were not fully identical. In addition, the measured approaching speed is based on estimation from camcorder camera recording. With respect to the length of change interval, it is not considered as a contributing factor at any of intersections, and therefore the dilemma zone issue was not investigated. Finally, all recorded data was limited to through movements only, and no concurrent safety data was available to be considered in the analysis.

To conduct the study, two levels of comparisons were considered, first is to compare each two similar (coupled) intersections (across groups with approximately the same conditions of shape, grade, traffic volume, and approaching speed), the second level is comparing between the two groups.

3. Data Analysis

The collected field data at the six signalized intersections were analyzed to estimate the drivers' compliance proportions at each intersection and the approach speed at various distances from the traffic signals line.

Scatter plots for the approaching speeds at each intersection showing the relationships between the average approach speed (in kilometers per hour) at Y-axis with various distances from the traffic light line (in meters) at X-axis are shown in Figures 1 and 2. Figure 1 includes the first set of intersections, while Figure 2 includes the second set of intersections, respectively.

Statistical analyses were conducted to answer the following questions (5% significance level):

1- Do drivers speed above the average approaching speed during the flashing green period?
2- Does the approaching speed vary based on the vehicle location upstream of traffic signal line?
3- Is there any significant difference between the two sets of intersections with respect to drivers' compliance (proportions of red light runners)?
4- Is there any significant difference between the two sets of intersections with respect to the rates of vehicles crossing during change interval?

In order to answer the previous four questions, hypotheses testing were conducted in the following order:

1- Compare the mean approaching speed to posted speed for the two sets using t-test.
2- Compare the mean approaching speed (between and within the two sets of intersections) at different distances from traffic signal line using t-test.

Proportion tests between the two types of intersections, the ones operating with flashing green and those operating without flashing green in terms of number of vehicles crossing on red; number of vehicles crossing on change interval; and number of vehicles jumping before green.

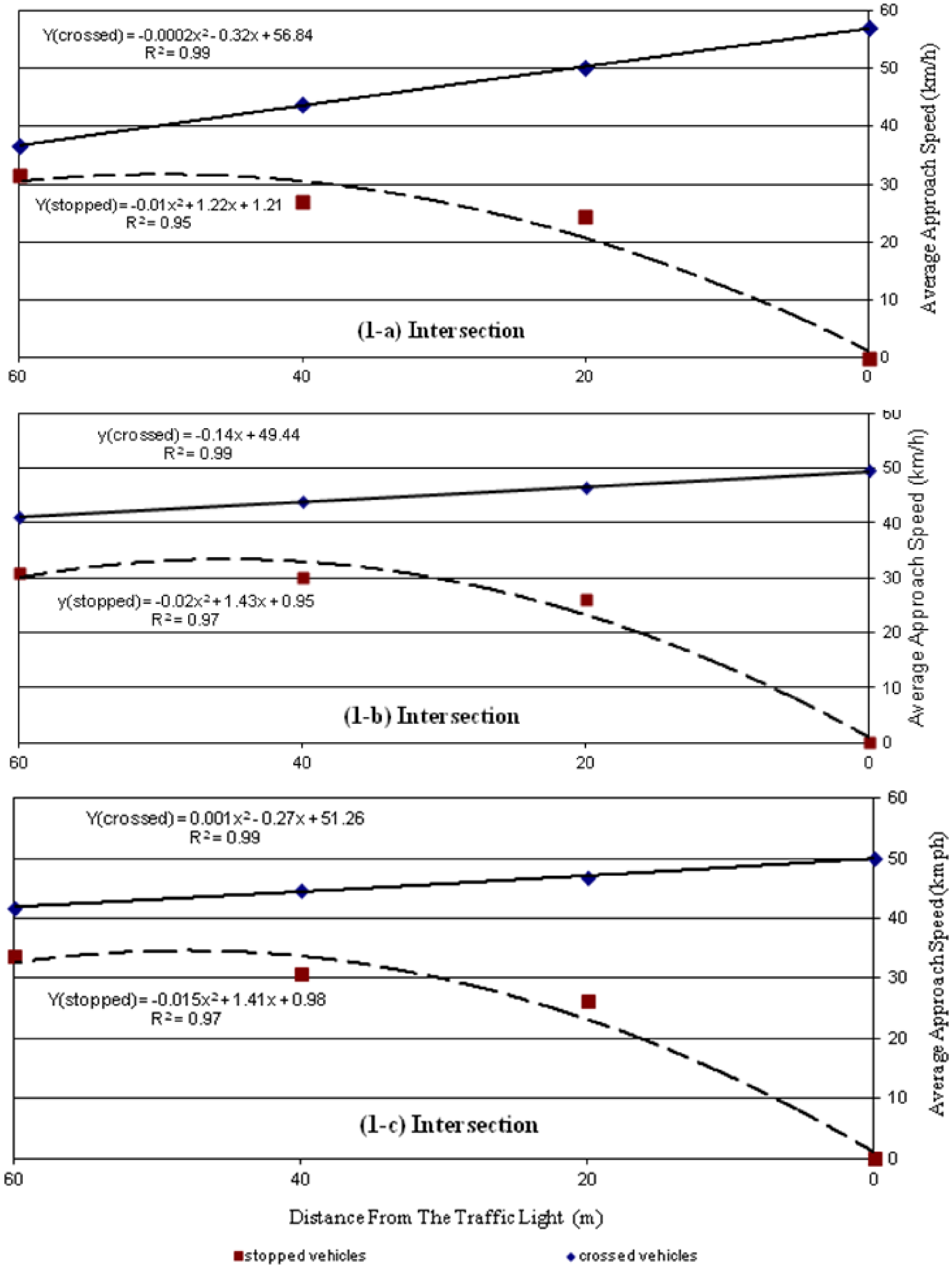

Figure 1: Approaching Speed for First Set Signalized Intersections (with flashing green)

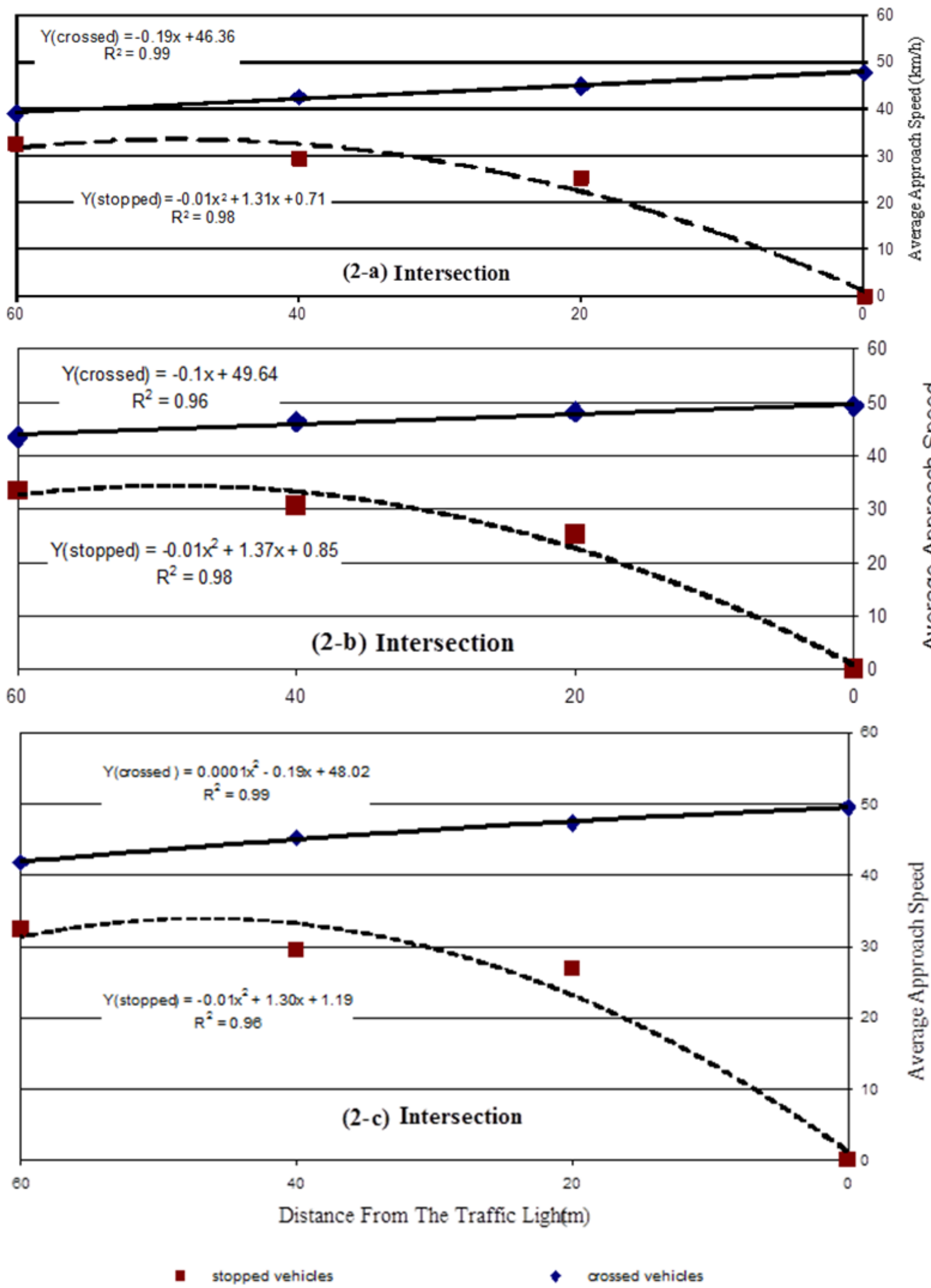

Figure 2: Approaching Speed for Second Set Signalized Intersections (without flashing green)

Responding to the first question, t-test for two samples with unknown and unequal variances was conducted to investigate if a significant difference in average approach speeds at 60 m distance upstream the traffic signal can be found. The first sample includes signalized intersections operating with flashing green, and the second sample includes signalized intersections operating without flashing green. Table1 shows the t-test results for stopping and crossing actions.

Table 1: t-test results for the average approaching speed between the two sets

Action	d.o.f.	t- value	P-value	Criteria for Rejection	Significant difference
Stopped vehicles	135	- 0.21	0.61	$\vert t_o \vert > 1.96$	No
Crossed vehicles	355	+ 0.31	0.38	$\vert t_o \vert > 1.96$	No

To answer the second question, t-test with unknown and unequal variances was conducted to investigate the mean approaching speed at different distances upstream of the traffic signal line. Table 2 shows the results of the testing between the two operating conditions at various distances upstream traffic signal line at (0 m, 20 m, 40 m, and 60 m) for both stopped and crossed vehicle actions.

Table 2: t-test results for the average approaching speed by distance for stopped and crossed vehicles between the two sets

Action of Vehicles	Distance (m)	d.o.f.	t-value	P-value	Rejection Criterion	Significant Difference
Stopped	20	132	- 0.66	0.25	$\vert t_o \vert > 1.96$	No
	40	135	- 1.07	0.14	$\vert t_o \vert > 1.96$	No
	60	134	- 0.85	0.20	$\vert t_o \vert > 1.96$	No
Crossed	0	354	+ 2.37	0.01	$\vert t_o \vert > 1.96$	Yes
	20	357	+ 0.72	0.24	$\vert t_o \vert > 1.96$	No
	40	357	- 0.63	0.26	$\vert t_o \vert > 1.96$	No
	60	357	- 1.59	0.05	$\vert t_o \vert > 1.96$	No

Hypothesis testing is used to make inference about the proportion of vehicles passing on red interval, change interval, and proportion of vehicles jumping before green phase between the two types of traffic signal devices. The testing is conducted using z-test. The testing results are tabulated in Table 3.

Table 3: Results of proportion z-test between the two sets

Vehicles Condition	Passing on Red	Passing on Change interval	Jumping before Green
Z	- 0.26	+ 20.07	- 4.84
P-value	0.41	0.0	0.0
Rejection Criteria	$\vert z \vert > 1.96$	$\vert z \vert > 1.96$	$\vert z \vert > 1.96$
Difference	No	Yes	Yes

4. Results

The results of this research paper are presented and discussed in this section in the same order that the questions are raised earlier. For the first question “Do drivers speed above the average approaching speed during the flashing green period?”, Table 4 summarizes the speeds statistics (min., max., and range) of the approaching vehicles at all intersections, the recorded speed are reported at 30 m upstream of the signal location, where the first set is intersections operating with flashing green and the second set related to intersections operating without flashing green.

Table 4: Approaching speed statistics for each intersection at 30 m upstream signal traffic line

Set No.	Intersection	Min. Speed (km/h)	Max. Speed (km/h)	Range (km/h)	Posted Speed (km/h)
1st Set	1 - a	29	47	18	60
	1 – b	30	44	14	60
	1 – c	26	45	19	60
2nd Set	2 - a	33	47	14	70
	2 – b	31	42	11	60
	2 - c	31	41	10	70

It is clear that stopping vehicles drive below posted speed, while crossing vehicles drive above posted speed at both sets of intersections. However, variation in speed between stopping and crossing vehicles during the change interval is risky and might lead to crashes, especially as vehicles approaching intersection. Results do not show any difference between the two types of intersections (flashing green and traditional change interval traffic signals).

To answer the second question "Does the approaching speed vary based on the vehicle location upstream of traffic signal line?" two tests were done, first t-test is used to make inference about the mean approaching speed between flashing green and traditional yellow change interval for both, stopped and crossed vehicles. Table 1 summarizes the results showing that no significant difference is detected at 95 % confidence level. The second test is used to detect whether the approaching speed within the above groups are significantly difference at different distances from the signal location. The same t-test is used to make inference about the approaching speed at (0, 20, 40, and 60) meters upstream the traffic signal line for both stopped and crossed vehicles.

The two sets of interest were signals operating with flashing green versus signals operating without flashing green. Not surprising, no significant difference is detected at all distances, with only one exception at distance zero from the signal location (at the line of traffic signal), the average approaching speed of the crossing vehicles at signals operating with flashing green is significantly different than the average approaching speed of the crossing vehicles at signalized intersections operating with traditional yellow change interval. Table 2 summarizes the results.

Finally, Table 4 summarizes the results answering the last questions "Are there any significant differences between the two sets with respect to the proportions of vehicles passing on red, change interval, and proportions of vehicles jumping before green phase". A z-test is used to make inference about the proportions of two populations. The two populations are vehicles entering intersections operating with flashing green change interval and vehicles entering intersections operating without flashing green change interval. Test results show that there is no significant difference of the proportion of vehicles crossing on red between the two sets of intersections, while significant difference is detected for the proportion of vehicles crossing during change interval or jumps before green. However, results showed a positive z-value for crossing during change interval, and a negative z-value for jumping before green.

5. Findings

Significant differential approaching speed is detected within 60 m from signalized intersections during change interval period due to differences in drivers' reaction during change interval period, where some drivers decided to cross the intersection while others decided to stop on the intersection. No significant difference in approaching speed across the two groups of drivers, who stopped or passed the intersection, is detected based on type of change interval operation (operating with flashing green light or operating without flashing green). However, the average approach speed of vehicles crossing intersections that operate with flashing green change interval is higher than the average approach speed for vehicles crossing intersections which operate without flashing green.

The proportion of vehicles crossing intersections during flashing green change interval is significantly higher than the proportion of vehicles crossing the intersections during change interval at intersections that operate without flashing green. The proportion of vehicles jumps before green on intersections operating with flashing green light is lower than the proportion of vehicles jumps before green on intersections operating without flashing green.

The relationship between average approach speed and distance upstream traffic light line is modeled as a positive linear relationship for vehicles passing the intersection and modeled as a negative non-linear relationship for stopped vehicles. This indicates that crossing vehicles accelerate at a constant base, while stopped vehicles decelerate at an increasing base until stopping.

6. Recommendations

Further research must investigate the impact of using flashing green at signalized intersections before adopting and widely using this technique. It is recommended to study drivers' behavior when vehicles approaching the intersection during change interval to develop an understanding about the contributing factors to drivers' decision (speed, stopping versus passing, or other behaviors such as lane changing). Such factors are geometry, configuration, signal phasing and timing sequence. Guidelines should be developed to control such application. Future research will expand the sample size to cover wide spectrum of intersections allover Jordan, and will consider the crash history records at each studied intersection. The monitoring process will cover before and after using the flashing green technique to investigate the gradual change in driving behavior imposed through the changing process in operating techniques.

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