DRIVER PERFORMANCE THROUGH THE YELLOW PHASE USING VIDEO CAMERA AT URBAN SIGNALIZED INTERSECTIONS

Article *in* Transport Problems · January 2021

DOI: 10.21307/tp-202X-0XX


Bara W. Al-Mestarehi
Jordan University of Science and Technology


Ahmad H. Alomari
Yarmouk University


Mohammed Taleb Obaidat
Jordan University of Science and Technology; Jadara University

 DOI: 10.21307/tp-202X-0XX

Keywords: driver behavior; signalized intersections; red light running; yellow phase

Bara' W. AL-MISTAREHI*
Jordan University of Science & Technology (JUST)
P.O. Box 3030 - Irbid 22110, Jordan
Ahmad H. ALOMARI
Yarmouk University (YU)
P.O. Box 566 - Irbid 21163, Jordan
Mohammed T. OBAIDAT, Areen A. AL-JAMMAL
Jordan University of Science & Technology (JUST)
**Corresponding author.* E-mail: bwmistarehi@just.edu.jo

DRIVER PERFORMANCE THROUGH THE YELLOW PHASE USING VIDEO CAMERA AT URBAN SIGNALIZED INTERSECTIONS

Summary. The main objective of this research is to examine the influencing parameters of driver performance through the yellow phase at urban signalized intersections with and without Red-Light Running (RLR) cameras. Data were collected to include the intersection type, vehicle type, turning movement type, vehicle position in a platoon or not, the presence of RLR cameras, green light flash devices, pedestrians, and pavement markings. Two thousands-hundred and sixty-eight driver observations were extracted. Only 33.3% of the drivers stopped before the stop line, 59% of the drivers passed the intersection through the yellow phase, while 7% of the drivers committed RLR violations. Results showed that drivers were extra likely to stop before the stop line through the yellow phase at locations with RLR cameras, green light flash devices, presence of pedestrians, pavement marking, and at four legs intersection. Chi-square tests indicated that all parameters had a significant impact on driver performance, except for the turning movement type.

1. INTRODUCTION

In a signalized intersection, incorrect driver decisions through the yellow phase guide to Red-Light Running (RLR) violations or crashes, such as right-angle, left-turn, and rear-end crashes. RLR can be defined as "to pass through an intersection when traffic light has turned red" [1]. RLR is one of the most common elements of traffic crashes at signalized intersections [2]. Some of these RLR violations occurred because of the existence of the drivers in the dilemma zones through the yellow phase. Based on Gazis-Herman-Maradudin (GHM) model [3], a driver cannot safely stop the vehicle at a distance closer than the minimum stop distance before the stop line. Also, the driver cannot safely cross the intersection during the yellow phase at a distance more significant than the maximum crossing (clearance) distance. At the zone between the minimum and maximum stop distance, the driver can neither safely stop before the stop line nor safely cross the intersection during the yellow phase, which is called the dilemma zone.

Dilemma zone can be classified into two types: type I and type II dilemma zones. Type I, a dilemma place described as "the area of an approach to a signalized intersection where a driver can neither stop comfortably nor safely clear the intersection at the start of yellow" [3]. It occurred because of incorrect geometric design and proper traffic signal timing [4; 5]. Type II dilemma zone or indecisive zones can be defined as "an area where the driver is indecisive about stopping or crossing when confronted with a yellow signal and is attributed to the complications in the driver decision-making process" [6]. It occurs because of the driver's decision during the yellow phase. So, the dilemma zone should be studied to eliminate it as possible and to raise traffic security at the signalized intersection.

The size of dilemma zones depends on the vehicle speed at the onset of the yellow phase, vehicle position at the onset of the yellow phase, acceleration and deceleration rates, driver decision, yellow phase interval, pavement surface conditions, and other factors [7]. When the driver is traveling at speed slower than the speed limit, an option zone will be created, while when the driver is traveling at speed higher than the speed limit, a dilemma zone will be created [8].

Globally traffic crashes are ranked as the 9th leading cause of death [9]. Every year about 1.3 million people die in traffic crashes, and up to 50 million are injured worldwide [10]. Over the last several years, in the United States, an average of 25% of traffic fatalities and 50% of all traffic injuries are intersection related [11]. Also, there were more than 6 million reported related to intersections crashes, where more than 15,000 were fatal crashes [10]. Moreover, the number of traffic crashes at signalized intersection causes of red-light running are more than 100,000 crashes and cause 1,000 fatalities every day [12]. In Jordan, 150,226 crashes were recorded in 2017, which caused 685 fatalities, 16,246 injuries, and the cost was approximately estimated to be 308 million Jordan dinars [13]. The number of traffic crashes related to RLR violations in 2018 was 155 crashes [14]. These statistics show a high number of crashes and indicate traffic crashes are a severe problem for Jordan and all countries in the world. This research will shed light on the driver behavior during the yellow phase at urban signalized intersections with and without RLR cameras in Jordan.

2. LITERATURE REVIEW

Driver actions during the yellow phase can be classified into three groups: aggressive, normal, and conservative based on their decision “stop/go decision” and critical distance to stop line at the onset of the yellow phase. Conservative drivers can be defined as “drivers who take the stop action even though they can proceed through the intersection during the yellow phase” [15]. In comparison, aggressive drivers can be defined as “drivers who aggressively pass the intersection during the yellow phase even though they are quite far away from the stop line” [15].

The driver “stop/go” action through the yellow phase depends on many parameters like vehicle distance to the stop line at the start of the yellow phase, vehicle type, vehicle position, turning movement type, pavement surface conditions, traffic volume, traffic signal timing, number of approach lanes, signal coordination, and the presence of RLR cameras. Various researchers have been studied the influencing parameters on the driver performance in urban, suburban, and rural areas in Australia, USA, Europe, and Asia, such as vehicle distance to stop line at the start of the yellow phase, vehicle type, vehicle position, intersection type, presence of RLR cameras, presence of flash green devices, presence of pedestrians, presence of countdown timers, traffic signal timing and demographic driver characteristics like age, gender, and using cell phones through driving.

It was found that vehicle distance to stop line, vehicle type, vehicle speed, flash green device, using cell phones through driving, and social context include, age and gender had a significant impact on the driver performance through the yellow phase [7, 16 – 29]. Bao et al. [23] results explained that drivers were extra likely to reach the intersections with green flash devices. Also, Savolainen et al. [22] found that the presence of flash green devices raised the probability of the drivers who take stop-action through the yellow phase. Moreover, Kim at el. [30] showed that when the traffic signal was installed away from the stop line, the probability of going through the yellow phase increased.

Lum and Wong [18], Gates et al. [31], and Savolainen et al. [22] found that drivers at signalized intersections with RLR cameras were extra likely to stop through the yellow phase. Gates and Noyce [32] and Alex et al. [16] found that vehicle type had a key influence on the deceleration rates and RLR occurrence. Likewise, Sun et al. [33] indicated that vehicle type significantly impacted the distribution of type one and typed two dilemma zones. Yan et al. [34] showed that pavement marking reduced the probability of risky go and conservative decisions through the yellow phase. Also, Gates et al. [31] indicated that drivers at intersections with short yellow phases were extra likely to take stop action, while drivers at intersections with long cycle length and red clearance intervals were extra likely to take go-action through the yellow phase. El-Shawarby et al. [35, 36] and Rakha et al. [17] indicated that time to the intersection and roadway grade had a meaningful impact on the driver perception reaction time while driver age did not affect it. Similarly, Caird et al. [37] studied the effect of yellow light onset time on older and younger drivers' perception response time (PRT) in Calgary, Canada. Results showed that the measured perception-reaction time did not affect by driver age. While time to stop line had a significant effect on the perception-reaction time. Moreover, younger drivers showed more significant acceleration and deceleration rates than older drivers. Finally, older drivers were less likely to pass the intersection than other age groups. Awad et al. [38] showed that delay, average annual daily traffic (AADT), and presence of RLR cameras had a significant impact on the RLR violations. Hussain et al. [39] indicated that the probability of cross decision during the yellow phase increased at green LED dynamic light (G-LED) condition compared with a controlled condition, which means G-LED condition improves efficiency signalized intersection. Also, the G-LED condition assists the driver in making comfortable and safe crossing decision. Also, Hussain et al. [40] found that innovation countermeasures and speed at the onset of the yellow phase significantly affected the RLR violations. Besides, female drivers are likely to be more aggressive than male drivers.

Yang at el. [7] indicated that the percentage of the drivers taking stop decisions at the intersection without the countdown timer device was more significant than the intersections without countdown timer devices. Also, Long, Liu, and Han [41] studied the impact of countdown timer on driving maneuvers after the yellow onset at four urban signalized intersections in Changsha city, China. Results showed that intersections with countdown timers assist the driver in making an appropriate decision during the yellow phase, reducing rear-end accidents that cause conservative stopping and right-angle accidents that cause aggressive crossing during the yellow phase. Similarly, Huey and Ragland [42] studied driver behavior changes resulting from pedestrian countdown signals in Berkeley, United States. Results showed that the total number of vehicles stop or enter the intersection after the green phase signal without pedestrian countdown timer was higher than the intersection with pedestrian countdown timer. Palat and Delhomme [43] showed that time pressure and social context had a significant effect on driver behavior during the yellow phase, where these factors increased the probability of the driver to pass the intersection during the yellow phase. Shen and Wang [44] explored how drivers respond to flashing green at signalized intersections in Yangzhou, China. Results showed that the probability of a go decision is higher when the stop line's distance is shorter, or the operating speed is higher. Swake et al. [45] studied driver response to the phase termination at a high-speed signalized intersection in Oregon, United States. Statistical results showed that driver behavior model of the type two dilemma zone is affected by driver decision, vehicle deceleration rates, and brake response times. Also, driver simulator results can be used as an effective method to predict driver behavior during the yellow phase at signalized intersections under the given conditions.

Several studies focused on investigating driver behavior during the yellow phase and the influence factors on the driver decisions at signalized intersections in recent years. Many of these studies have been carried out in the United States, Europe, China, Qatar, and other countries, to identify the boundaries of dilemma zones and to improve traffic safety at a signalized intersection. However, in Jordan, driver behavior during the yellow phase has not been given full attention in traffic and safety research. This study used video cameras to record traffic signal indications, driver actions, and influence parameters on the driver performance through the yellow phase at urban signalized intersections. The utilization of video cameras, at least locally in Jordan and the middle east, in recording, archiving, and analyzing the data gives the researcher an opportunity to review all the gathered information and provide accurate results. Besides, there is no previous research, nationally or globally, that studied the effect of intersection type and the presence of pedestrians on driver performance through the yellow phase at urban signalized intersections. The results of this study can contribute directly to the improvement of safety strategies at signalized intersections. This study investigated the influencing factors on the driver decision, including the presence of RLR cameras, flash green device, presence of pedestrians, pavement marking condition, intersection type, vehicle type, movement type, and vehicle position.

3. RESEARCH OBJECTIVES

The objectives of this research can be summarized as follows:

1. To classify driver actions through the yellow phase at urban signalized intersections into three groups, stop before the stop line, cross the intersection before the end of the yellow phase, cross the intersection after the end of the yellow phase.
2. To investigate the main possible influencing parameters on driver performance through the yellow phase at urban signalized intersections.
3. To suggest some improvement strategies to reduce aggressive driver performance through the yellow phase and raise safety at urban signalized intersections.

3. METHODOLOGY

Eight urban signalized intersections were selected in Irbid City, Jordan. Four intersections were with RLR cameras, and different four intersections were without RLR cameras. In addition to the intersection type, further field data were observed to cover several characteristics such as subject approach, posted speed limit (km/hr), number of lanes on target way (lane), amount of cross lanes by the target way (lane), intersection width (meter), an approach traffic volume per lane (vehicle/hour), lane width (meter), number of legs (three or four legs), presence of RLR cameras (yes, no), presence of flash green device (yes, no), presence of pedestrian (low pedestrian activity, medium to high pedestrian activity), and pavement marking condition such as lane markings, stop line, and crosswalk (exist/absent). Traffic signal timing data were collected before the field data observation. Only one approach from each signalized intersection was studied. All selected sites had a split phasing preference, where the right-of-way was assigned to all movements of a particular approach, followed by all opposing approach movements. The site selection criteria are presented in Tab. 1.

Tab. 1

Criteria of Site Selection

Check	Criteria
Channelization	Island
Traffic Condition	Mixed
Stream	Congestion
Right Turn Movement	Channelized
Signal System	Fully Actuated
Speed Limit	60 Km/h
Vehicle Type	Passenger and Heavy Vehicle

Driver behavioral data were collected at peak periods through weekdays of July, August, and September 2019 in good weather and dry pavement conditions under mixed traffic conditions. Video camera (Canon EOS 1300Dω/EF-S18-55 III kit) was used and placed for two hours for each selected approach at a sufficient height upstream of the intersection to record traffic signal indications, driver actions and parameters influencing on the driver performance through the yellow phase. The measuring tape was used to measure geometric design characteristics such as lane width (meter) and intersection width (meter). The actual intersection width can be defined as the distance from the edge of the subject approach (upstream) to the opposite edge approach (downstream). Also, fixed poles and trees were used as reference points to identify the approximate status vehicle position at the start of the yellow phase. Tab. 2 and Tab. 3 present the summary of data collection.

Tab. 2

Intersection Characteristic

Intersection	T1	T2	T3	T4	T5	T6	T7	T8
Studied Approach	NB	SB	WB	NB	EB	EB	WB	EB
No. of Lanes Crossed	8	9	9	8	5	5	6	10
No. of Lanes	3	2	4	3	4	4	3	3
Lane Width (m)	3	3.5	3	3.57	2.925	3.12	2.933	3
Intersection Width (m)	23.2	37	31	39	32	33.5	27.5	43.7
Traffic Volume (Veh/hr)	476	382	394	502	342	359	221	272

No. of Phases	4	4	4	4	3	3	4	4
No. of Legs	4	4	4	4	3	3	4	4
Grade	Level	Upgrade	Level	Level	Level	Level	Level	Level

* NB: North Bound, WB: West Bound, SB: South Bound, EB: East Bound.

Tab. 3

Traffic Signal Timing Data

Intersection	T1	T2	T3	T4	T5	T6	T7	T8
Cycle (Sec)	131	139	109	146	64	82	112	126
Red (Sec)	95	102	75	104	44	56	82	95
Yellow (Sec)	4	3	2	3	5	3	2	3
Green (Sec)	30	32	30	37	15	21	26	26
Green Split	0.229	0.23	0.275	0.253	0.234	0.256	0.232	0.206
All Red (Sec)	2	2	2	2	0	2	2	2
RLR	Yes	Yes	Yes	Yes	No	No	No	No
Pavement Marking	Yes	Yes	Yes	Yes	No	No	Yes	No
Green Flash	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Pedestrian	Low	Medium to High	Low	Low	Low	Low	Medium to High	Low
Coordinates	32°32'36.7"N 35°52'50.3"E	32°31'53.8"N 35°51'08.9"E	32°32'05.2"N 35°51'36.4"E	32°32'33.1"N 35°51'31.8"E	32°33'00.3"N 35°51'44.1"E	32°32'41.5"N 35°52'29.1"E	32°33'24.3"N 35°50'58.3"E	32°33'26.8"N 35°51'47.8"E

The recorded videos were played using VEGAS Pro 16 frame by frame video player software [46]. For each cycle in the studied traffic signal, the following data were extracted:

1. For vehicle distance, fixed poles and trees were used as reference points to identify the approximate status vehicle position, as shown in Fig. 1.
2. Driver actions, in three possible scenarios: stopped, passed the intersection through the yellow phase, or passed the intersection at the end of the yellow phase. A video camera extraction is based on visualization.
3. Vehicle position in a platoon or not. If the distance between the following vehicles is two seconds or less, the vehicle position was recorded in the platoon. However, if the distance between the following vehicles higher than two seconds, the vehicle position was recorded not in the platoon. It was extracted from a video camera based on visualization.
4. Vehicle lane position, headed to through movement, left, or U-turn, it was extracted from video camera based on visualization.
5. Vehicle types:
   - Passenger vehicles including (regular cars, taxi, pickups, and vans with two axles), or
   - Heavy vehicles including (trucks and buses), it was extracted from video camera based on visualization.

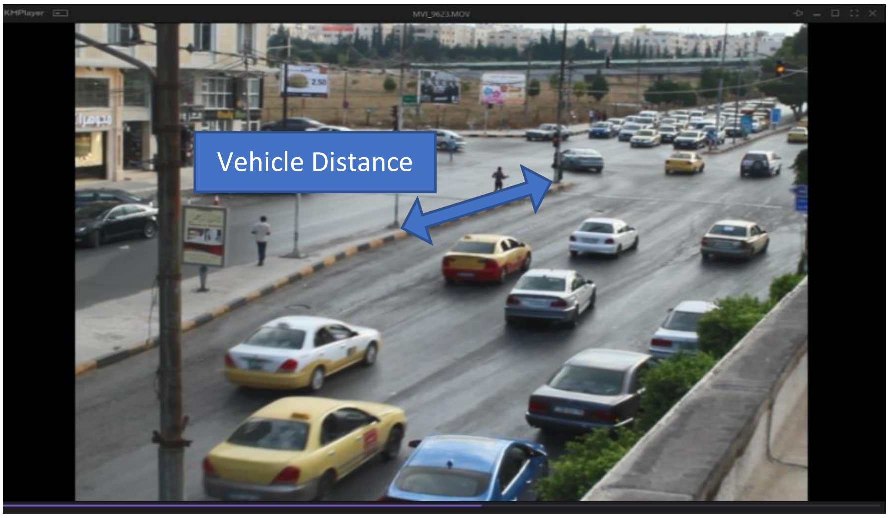

Fig. 1. Screenshot of intersection (T3) video

A Chi-Square test was used to examine associations between categorical variables. The null hypothesis of the test is that no relationship occurs on the categorical variables in the population, whereas the alternative hypothesis is that there is a relationship between the categorical variables. This test is most commonly applied to assess tests of independence when using a crosstabulation (two-way table). Crosstabulation shows the distributions of two categorical variables together, with the intersections of the categories of the variables appearing in the cells of the table. The test of independence evaluates whether a relationship exists between the two variables by comparing the observed pattern of responses to the pattern that would be expected if the variables were genuinely independent of each other.

4. RESULTS

The data extraction step resulted in 2168 observations, including stop, pass, and RLR violations action. Only 721 (33.3%) of the observations stopped before the stop line, 1296 (59.8%) of the observations passed through the intersection through the yellow phase, and 151 (7%) of the observations passed through the same phase, which means they committed RLR violations. The distribution of results can be shown in Fig. 2.

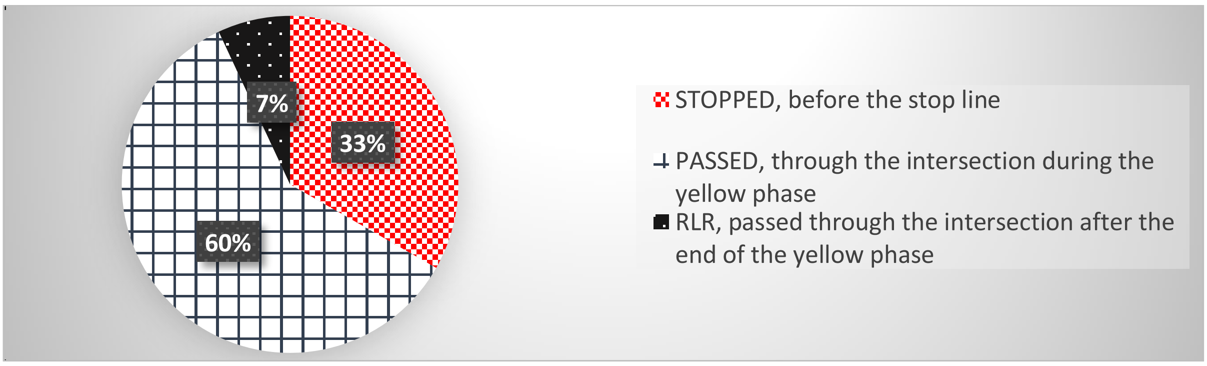

Fig. 2. Distribution of Observations at all Studied Intersections

Presence of RLR cameras, presence of flash green devices, presence of pedestrians, pavement marking conditions, intersection type, vehicle type, turning movement type, and vehicle position were considered as expected parameters on the driver performance through the yellow phase. Data analysis results showed that drivers were extra likely to stop before the stop line through the yellow phase at locations with RLR cameras, with the flash green light device, with high presence of pedestrians, with pavement marking, and at four legs intersection. Also, Vehicles in-platoon position had a higher percentage of pass action 69.8% than vehicles not-in-platoon position 46.6%. Moreover, Van had the highest percentage of pass action among all types of vehicles, 77%, and the taxi had the lowest percentage of pass action at 54.5%. On the other hand, truck and pickup had a similar percentage of pass 64% and 54.9%, respectively. Tab. 4 displays the sum and percentage of driver performance data for all signalized intersections studied.

A Chi-square test was applied to check independence between variables of categorical, where the null and alternative hypothesis are:

– H_0: the signalized intersections, with the studied variable, are independent.
– H_1: the signalized intersections, with the studied variable, are not independent.

There is no relationship in the null hypothesis of the Chi-Square test between variables of categorical in the population, while the observed relationship between variables of categorical in the population in the alternative hypothesis. Chi-square tests showed that the presence of RLR cameras, presence of flash green devices, presence of pedestrians, pavement marking conditions, intersection type, vehicle type, and vehicle position had a meaningful impact on the driver performance through the yellow phase, but turning movement type does not. Chi-square test, phi and Cramer's' test results for all studied parameters are presented in Tab. 5 and Tab. 6.

Tab. 4

Sum and percentage of all influencing factors

Influencing parameters			**Action**		
			Stop	**Pass**	**RLR**
Presence of RLR Cameras	**Yes** (722, 33%)	Count	406	305	11
		Percentage	**56.3%**	**42.2%**	**1.5%**
	No (1446, 67%)	Count	315	991	140
		Percentage	**21.8%**	**68.5%**	**9.7%**
Presence of Flash Green Device	**Yes** (1477, 68%)	Count	622	772	83
		Percentage	**42.1%**	**52.3%**	**5.6%**
	No (691, 32%)	Count	99	524	68
		Percentage	**14.3%**	**75.8%**	**9.8%**
Presence of Pedestrian	**Low** (1861, 86%)	Count	576	1156	129
		Percentage	**31.0%**	**62.1%**	**6.9%**
	Medium to High (307, 14%)	Count	145	140	22
		Percentage	**47.2%**	**45.6%**	**7.2%**
Pavement Marking Condition	**With** (887, 41%)	Count	464	392	31
		Percentage	**52.3%**	**44.2%**	**3.5%**
	Without (1281, 59%)	Count	257	904	120
		Percentage	**20.1%**	**70.6%**	**9.4%**
Intersection Type	**3-Legs** (1283, 59%)	Count	256	894	133
		Percentage	**20%**	**69.7%**	**10.4%**
	4-Legs (885, 41%)	Count	465	402	18
		Percentage	**52.5%**	**45.4%**	**2.0%**
Vehicle Type	**PC** (1535, 71%)	Count	513	911	111
		Percentage	**33.4%**	**59.3%**	**7.2%**
	Taxi (246, 11%)	Count	102	134	10
		Percentage	**41.5%**	**54.5%**	**4.1%**
	Pickup (83, 4%)	Count	21	55	8
		Percentage	**25.6%**	**66.3%**	**8.5%**

	Van (113, 5%)	Count	26	77	10
		Percentage	**23.0%**	**68.1%**	**8.8%**
	Truck (136, 6%)	Count	42	87	7
		Percentage	**30.9%**	**64.0%**	**5.1%**
	Bus (55, 3%)	Count	17	32	6
		Percentage	**30.9%**	**58.2%**	**10.9%**
Movement Type	**Left** (1034, 48%)	Count	345	634	55
		Percentage	**33.4%**	**61.3%**	**5.3%**
	U-Turn (90, 4%)	Count	32	52	6
		Percentage	**35.6%**	**57.8%**	**6.7%**
	Through (1044, 48%)	Count	344	610	90
		Percentage	**33.0%**	**58.4%**	**8.6%**
Vehicle Position	**Platoon** (1231, 57%)	Count	306	859	66
		Percentage	**24.9%**	**69.8%**	**5.4%**
	Not Platoon (937, 43%)	Count	415	437	85
		Percentage	**44.3%**	**46.6%**	**9.1%**

Tab. 5

All results of chi-square test for studied influencing factors

Influencing factors		**Tests (Chi-Square)**		
		amount	**D.f**	**Asymp.sig. (two-sided)**
RLR Cameras	Pearson Chi-Square	273.531	Two	0.0
	Likelihood Ratio	277.873	Two	0.0
	Linear-by-Linear Association	262.327	One	0.0
Flash Green Light	Pearson Chi-Square	165.055	Two	0.0
	Likelihood Ratio	180.334	Two	0.0
	Linear-by-Linear Association	144.716	One	0.0
Presence of Pedestrian	Pearson Chi-Square	33.046	Two	0.0
	Likelihood Ratio	31.925	Two	0.0
	Linear-by-Linear Association	20.360	One	0.0
Pavement Marking Condition	Pearson Chi-Square	250.840	Two	0.0
	Likelihood Ratio	252.181	Two	0.0
	Linear-by-Linear Association	228.555	One	0.0
Intersection Type	Pearson Chi-Square	271.013	Two	0.0
	Likelihood Ratio	278.525	Two	0.0
	Linear-by-Linear Association	263.180	One	0.0
Vehicle Type	Pearson Chi-Square	19.645	Ten	0.033
	Likelihood Ratio	20.151	Ten	0.028
	Linear-by-Linear Association	3.897	One	0.048
Turning Movement Type	Pearson Chi-Square	9.055	Four	0.060
	Likelihood Ratio	9.120	Four	0.058
	Linear-by-Linear Association	2.185	One	0.139
Vehicle Position	Pearson Chi-Square	118.592	Two	0.0
	Likelihood Ratio	118.895	Two	0.0
	Linear-by-Linear Association	39.465	One	0.0
No. of Actual Cases	**2168**			

Tab. 6

Phi and Cramer's test results for all studied influencing factors

Influencing Factors	**N by N**	**Measures**		
			Value	**Approx.sig.**

RLR Cameras	N by N	Phi	0.355	0.0
		Cramer's V	0.355	0.0
Flash Green Light	N by N	Phi	0.276	0.0
		Cramer's V	0.276	0.0
Presence of Pedestrians	N by N	Phi	0.123	0.0
		Cramer's V	0.123	0.0
Pavement Marking Condition	N by N	Phi	0.340	0.0
		Cramer's V	0.340	0.0
Intersection Type	N by N	Phi	0.354	0.0
		Cramer's V	0.354	0.0
Vehicle Type	N by N	Phi	0.095	0.033
		Cramer's V	0.067	0.033
Turning Movement type	N by N	Phi	0.065	0.06
		Cramer's V	0.046	0.06
Vehicle Position	N by N	Phi	0.234	0.0
		Cramer's V	0.234	0.0
No. of Actual Cases	**2168**			

* N by N: Nominal by Nominal

5. DISCUSSION

As shown in Tables 4 to 6, the presence of RLR cameras, presence of flash green devices, presence of pedestrians, pavement marking conditions, intersection type, vehicle type, turning movement type, and vehicle position were investigated as influencing parameters on the driver performance through the yellow phase at the studied signalized intersections.

5.1 Presence of RLR Cameras

Results showed that 33% of the observations were recorded at signalized intersections with RLR cameras, and 67% without RLR cameras. Signalized intersections with RLR cameras given a higher percentage of stop action (56.3%) than signalized intersections without RLR cameras (21.8%), while signalized intersections without RLR cameras showed a higher percentage of pass action (68.5%) than ones with RLR cameras (42.2%).

The Pearson's chi-squared test showed significant difference at 95% confidence between signalized intersections with and without RLR cameras (x^2 = 273.531, DF = 2, p = 0.000 < 0.05). The null hypothesis that said the signalized intersections with and without RLR cameras are independent variables is rejected. These results agree with Gates et al. [31], Savolainen et al. [22], and Lum and Wong [18] results that concluded; the presence of RLR cameras had a significant impact on the driver performance through the yellow phase with an increase in the probability of stopping decision and RLR violations.

5.2 Presence of Flash Green Light

A total of 68% of the observations were recorded at signalized intersections with flash green light, and 32% without a flash green light. Data analysis results showed that signalized intersections without flash green light show a higher percentage of pass action (75.8%) and RLR violations (9.8%) and a lower percentage of stop action (14.3%), compared to signalized intersections with a flash green light (52.3%), (5.6%), and (42.1%) respectively. That refers to the presence of a flash green light, which helps drivers make their decision during the transition phase and reduce the frequency of RLR violations since they have earlier knowledge that the yellow signal will begin.

The Pearson's chi-squared test shown significant difference at 95% confidence between signalized intersections with and without flash green light (x^2 = 165.055, DF = 2, p = 0.000<0.05). The null hypothesis that said the signalized intersections with and without flash green light device are independent variables is rejected. These results of the presence of flash green devices agree with Gates et al. [47] and Savolainen et al. [22] results that concluded; the presence of green flashlight had a significant impact on driver behavior with the raising of the probability of early stopping. However, this result is contradicted with Bao et al. [23] results that said, drivers were extra likely to pass the intersections through the yellow phase at signalized intersections with green flashlight device. In summary, several studies concluded that the flashing green application leads to an increase in the number of rear-end collisions [4, 19, 48] and reduces the traffic signal capacity [49], although it reduces RLR violations.

5.3 Presence of Pedestrians

Findings revealed that 86% of the observations were recorded at intersections with low presence of pedestrians and 14% with medium to high pedestrians. Data analysis results revealed that signalized intersections with low pedestrians showed a higher percentage of pass action (62.1%) than a medium to high level of pedestrians (45.6%). On the other hand, signalized intersections with low presence of pedestrians showed a lower percentage of stop action (31%) than a medium to high level of pedestrians (47.2%).

The Pearson's chi-squared test showed significant difference at 95% confidence between signalized intersections with low or medium to high level of pedestrian activities (x^2 = 33.046, DF = 2, $p=0.000 <0.05$). The null hypothesis that said the signalized intersections with low, medium to high presence of pedestrians are independent variables is rejected. These results agree with Gates et al. [50] that said, the presence of pedestrians had a significant impact on driver performance through the yellow phase at urban and suburban signalized intersections. It means that drivers were extra likely to pass at locations with a low level of pedestrians. Proper signal settings for both vehicles and pedestrians, along with suitable enforcement can improve safety at urban signalized intersections.

5.4 Pavement Marking Condition

Five signalized intersections with pavement marking and three signalized intersections without pavement marking were included in this research. 41% of the observations were recorded at signalized intersections with pavement marking, and 59% without pavement marking. Data analysis results showed that signalized intersections without pavement marking show a higher percentage of pass action (70.6%) and RLR violations (9.4%) than signalized intersections with pavement marking (44.2%) and (3.5%), respectively. That is due to the presence of pavement marking warn the driver, and the presence of pavement marking depends on the presence of RLR camera at most signalized intersections.

The Pearson's chi-squared test showed significant difference at 95% confidence between signalized intersections with and without pavement marking (x^2 = 250.840, DF = 2, $p = 0.000 <0.05$). The null hypothesis that said the signalized intersections with and without pavement marking are independent variables is rejected. These results agree with Yan et al. [34] findings that concluded; pavement marking had a meaningful impact on driver performance through the yellow phase. It has reduced the probability of risky pass decisions and the frequency of RLR violations.

5.5 Intersection Type

Three-leg and four-leg signalized intersections were included in this research. Almost 59 % of the observations were recorded at three-leg signalized intersections, and 41% at four-leg signalized intersections. Data analysis results showed that three-leg signalized intersections show a higher percentage of pass action (69.7%) and RLR violations (10.4%) than four-leg signalized intersections (45.4%) and (2%), respectively. That is referring to conflict movements at three-leg intersections lower than four-leg intersections, making the pass and RLR violations more easily than four legs signalized intersections.

The Pearson's chi-squared test showed significant difference at 95% confidence between signalized intersections with different types of intersection (x^2 = 271.013, DF = 2, p = 0.000 <0.05). The null hypothesis that said three-leg and four-leg signalized intersections are independent is rejected.

5.6 Vehicle Type

Vehicle types were classified into five major categories, including passenger car, taxi, van, pickup, truck, and bus. Nearly 71% of the vehicles were classified as passenger cars, 11% taxies, 5% vans, 4% pickups, 6% trucks, and only 3% were buses. Data analysis results showed that the van had the highest percentage of pass action (77%) while the taxi had the lowest pass action percentage (54.5%). Truck and pick up had a similar percentage of pass action (64%) and (65.9%), respectively.

The person Chi-Square test shown significant difference at 95% confidence between different type of vehicles (x^2 = 19.645, df = 10, p = 0.033<0.05). The null hypothesis that said driver behavior during different types of vehicles are independent variables is rejected. These results agree with Alex et al. [16], Gates and Noyce [32], and Gates et al. [50] findings that concluded; vehicle type had a meaningful impact on driver performance through the yellow phase.

5.7 Turning Movement Type

Three types of movements were included in this research, through movement, left-turn movement, and U-turn movement. Approximately 48% of the observations were through movement, 48% left-turn movement, and 4% U-tern movement. Data analysis results showed that the percentage of pass action for through, left and U-turn movements close to each other, 58.4% for through movement, 61.3% for left movement, and 57.8% for U-turn movement. However, through movement has shown the highest percentage of RLR violations (8.6%).

The Pearson's chi-squared test shown no significant difference at 95% confidence between different types of movements (x^2 = 9.055, DF = 4, p = 0.060 >0.05). The null hypothesis that said turning movement types at signalized intersections are independent variables is accepted.

5.8 Vehicle Position

Almost 57% of the observations were in a platoon, and 43% were not in a platoon. Data analysis results showed that vehicles not in platoon show a higher percentage of RLR violations (9.1%) than vehicles in a platoon (5.4%). Also, vehicles in platoon show a higher percentage of pass action (69.8%) than vehicles not in a platoon (46.6%). That is referred to the following drivers' actions, which are affected by leading-drivers' decisions.

The Pearson's chi-squared test showed significant difference at 95% confidence between different type of vehicle position (x^2 = 118.592, DF=10, p=0.000<0.05). The null hypothesis that said vehicle position at signalized intersections is independent variables is rejected. This result agrees with Bao et al. [23] findings that concluded; vehicle position had a meaningful impact on driver performance through the yellow phase. In other words, the presence of the next vehicle with short headway had a considerable impact on the following driver action. Moreover, this result contradicted with Gates and Noyce [32] results that concluded; driver performance through the yellow phase did not affect by vehicle position in a platoon or not.

It should be noted that some other potentially influential factors on drivers' stop/go decisions at signalized intersections were omitted and not investigated in this study. Factors include geometric design characteristics, pavement surface conditions, travel speed, individual driver characteristics (including age, gender, presence of passengers in the vehicle or not), and actions performed by drivers like eating, smoking, and using cell phones. Also, this study investigated driver behavior during peak periods through weekdays at urban signalized intersections. Another potential limitation of this study is the low number of sites with three legs; future research could be conducted on these types of sites to account for this limitation. Future research should cover more signalized intersections during off-peak periods and within suburban and rural areas.

6. CONCLUSIONS

The purpose of this article is to examine the influencing parameters on the driver performance through the yellow phase. Eight urban signalized intersections with and without RLR cameras were selected. Video camera was used and placed for two hours at a sufficient height upstream of the intersection to record traffic signal indications, driver actions, and influence parameters on the driver behavior. Two thousand one hundred sixty-eight driver behavioral observations were extracted from data collection. Only 33.3% of the observations were stopped before the stop line, 59% of the observations were passed the intersection through the yellow phase, while 7% of the observations were passed the intersections after the end of the yellow phase (RLR violations).

Data analysis results showed that drivers were extra likely to stop before the stop line through the yellow phase at locations with RLR cameras, with the green light flash device, with high presence of pedestrians, with pavement marking, and at four legs intersection. Van had the highest percentage of pass action among all types of vehicles, 77%. While the taxi had the lowest percentage of pass action, 54.5%. In comparison, truck and pickup had a similar percentage of pass 64% and 54.9 %, respectively. Through, left, and U-tern movements had a close percentage of pass 58.4%, 61.3%, and 57.8%, respectively. However, through movement had the highest RLR violation rate. Also, vehicles in-platoon position had a higher percentage of pass action 69.8% than vehicles not-in-platoon position 46.6%. Chi-square tests showed that the presence of RLR cameras, presence of flash green devices, presence of pedestrians, pavement marking condition, intersection type, vehicle type, and vehicle position had a meaningful impact on the driver performance through the yellow phase but turning movement type does not.

In order to raise the safety at urban signalized intersections, several improvement strategies can be recommended based on this study and previous research, as follow:

1. RLR cameras must be deployed to all traffic intersections to raise the level of law enforcement.
2. Pedestrians' infrastructure, which in turn protects them and their conflicts with vehicles, should be improved at intersections to increase safety.
3. Enforcement stricter actions toward drivers who violated the red-light phase should be taken.
4. Traffic signal timing needs to be improved according to the proper traffic volume demands, geometric, and traffic control conditions.
5. Training and educational courses covering safety awareness and driving ethics must be reviewed and reconsidered by the authorities when given to new drivers, as well as for the existing drivers, to improve drivers' commitment and awareness at signalized intersections.

Further studies are recommended to investigate the effects of geometric design characteristics, pavement surface conditions, travel speed, individual driver characteristics (including age, gender, presence of passengers in the vehicle or not), and actions performed by drivers like eating, smoking, and using cell phone. Future research should also cover more signalized intersections during peak and off-peak periods at urban, suburban, and rural areas in different cities around the world.

REFERENCES

1. Naghawi, H., Al Qatawneh, B., & Al Louzi, R. Evaluation of Automated Enforcement Program in Amman. *Periodica Polytechnica Transportation Engineering*. 2018. 46(4). pp.201-206.
2. Zhang, Y., Yan, X., Li, X., Wu, J., & Dixit, V. V. Red-light-running crashes' classification, comparison, and risk analysis based on General Estimates System (GES) crash database. *International journal of environmental research and public health*. 2018. 15(6). 1290.
3. Gazis, D., Herman, R., & Maradudin, A., The problem of the amber signal light in traffic flow. *Operations Research*. 1960. *8*(1), pp.112-132.

4. ITE, Institute of Transportation Engineers. Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce. Publication No. IR-115. Department of Transportation, Federal Highway Administration (FHWA), United States. 2003.
5. Koonce, P., & Rodegerdts, L. Traffic signal timing manual (No. FHWA-HOP-08-024). Department of Transportation, Federal Highway Administration (FHWA), United States. 2008.
6. Abbas, M., Machiani, S. G., Garvey, P. M., Farkas, A., & Lord-Attivor, R. Modeling the dynamics of driver's dilemma zone perception using machine learning methods for safer intersection control. *Mid-Atlantic Universities Transportation Center*. 2014. No. MAUTC-2012-04.
7. Yang, Z., Tian, X., Wang, W., Zhou, X. and Liang, H., Research on driver behavior in yellow interval at signalized intersections. *Mathematical Problems in Engineering*. 2014. Vol. 2014, Article ID 518782, 8 pages.
8. Papaioannou, P. Driver behaviour, dilemma zone and safety effects at urban signalized intersections in Greece. Accident Analysis & Prevention. 2007. 39(1). pp.147-158.
9. WHO, World Health Organization. Global Status Report on Road Safety 2015. Available at: https://www.who.int/violence_injury_prevention/road_safety_status/2015/en/#:~:text=The%20Global%20status%20report%20on%20road%20safety%202015%2C%20reflecting%20information,rates%20in%20low%2Dincome%20countries.
10. NHTSA, National Highway Traffic Safety Administration. Traffic Safety Facts - 2016. Washington, DC20590. 2018.
11. FHWA, Federal Highway Administration. 2018. Intersection Safety. Available at: https://safety.fhwa.dot.gov/intersection
12. FHWA, Federal Highway Administration. 2007. Stop Red Light Running Facts and Statistics, U.S. Department of Transportation. FHWA Safety 2006. Available at: http://safety.fhwa.dot.gov/intersections/redl_facts.htm.
13. JTI, Jordan Traffic Institute. Traffic Accidents in Jordan, 2017. Amman, Jordan. Available at: https://www.psd.gov.jo/images/traffic/traffic2017.pdf
14. DOS, Department of Statistics, Jordan. 2020. Available at: http://dosweb.dos.gov.jo/ar/
15. Liu, Y., Chang, G.L., Tao, R., Hicks, T. and Tabacek, E. Empirical observations of dynamic dilemma zones at signalized intersections. *Transportation Research Record: Journal of the Transportation Research Board*. 2007. Vol. 2035. pp.122-133.
16. Alex, S., Isaac, K. P., & Varghese, V., Modelling Driver Behaviour at Signalized Intersection in Indian Roads 2. *Transportation Research Board (TRB) Annual Meeting*, Paper No. 13-0257, Washington D.C., United States, 2013.
17. Rakha, H., El-Shawarby, I. and Setti, J.R., Characterizing driver behavior on signalized intersection approaches at the onset of a yellow-phase trigger. *IEEE Transactions on Intelligent Transportation Systems*. 2007. 8(4), pp.630-640.
18. Lum, K.M. and Wong, Y.D., A before-and-after study of driver stopping propensity at red light camera intersections. *Accident analysis & prevention*. 2003. 35(1), pp.111-120.
19. Köll, H., Bader, M. and Axhausen, K.W., Driver behaviour during flashing green before amber: a comparative study. *Accident Analysis & Prevention*. 2004. 36(2), pp.273-280.
20. Li, J., Jia, X. and Shao, C., Predicting driver behavior during the yellow interval using video surveillance. *International journal of environmental research and public health*. 2016. 13(12), p.1213.
21. Tang, K., Xu, Y., Wang, F. and Oguchi, T., Exploring stop-go decision zones at rural high-speed intersections with flashing green signal and insufficient yellow time in China. *Accident Analysis & Prevention*. 2016. 95, pp.470-478.
22. Savolainen, P.T., Sharma, A. and Gates, T.J., Driver decision-making in the dilemma zone–Examining the influences of clearance intervals, enforcement cameras and the provision of advance warning through a panel data random parameters probit model. *Accident Analysis & Prevention*. 2016. 96, pp.351-360.

23. Bao, J., Chen, Q., Luo, D., Wu, Y. and Liang, Z., Exploring the impact of signal types and adjacent vehicles on drivers' choices after the onset of yellow. *Physica A: Statistical Mechanics and its Applications*. 2018. 500, pp.222-236.
24. Palat, B. and Delhomme, P., What factors can predict why drivers go through yellow traffic lights? An approach based on an extended theory of planned behavior. *Safety science*. 2012. 50(3), pp.408-417.
25. Haque, M.M., Ohlhauser, A.D., Washington, S. and Boyle, L.N. Decisions and actions of distracted drivers at the onset of yellow lights. *Accident Analysis & Prevention*. 2016. 96, pp.290-299.
26. Lavrenz, S.M., Pyrialakou, V.D. and Gkritza, K., Modeling driver behavior in dilemma zones: A discrete/continuous formulation with selectivity bias corrections. *Analytic Methods in Accident Research*. 2014. 3, pp.44-55.
27. Xiong, H., Narayanaswamy, P., Bao, S., Flannagan, C. and Sayer, J., How do drivers behave during indecision zone maneuvers? *Accident Analysis & Prevention*. 2016. 96, pp.274-279.
28. Zhang, Y., Fu, C., & Hu, L. Yellow light dilemma zone researches: a review. *Journal of traffic and transportation engineering (English edition)*. 2014. *1*(5), 338-352.
29. Dong, S., & Zhou, J. A Comparative Study on Drivers' Stop/Go Behavior at Signalized Intersections Based on Decision Tree Classification Model. *Journal of advanced transportation, 2020*.
30. Kim, W., Zhang, J., Fujiwara, A., Jang, T. and Namgung, M., Analysis of stopping behavior at urban signalized intersections: empirical study in South Korea. *Transportation Research Record: Journal of the Transportation Research Board*. 2008. 2080, pp.84-91.
31. Gates, T., Savolainen, P. and Maria, H.U., Impacts of automated red-light running enforcement cameras on driver behavior. *Transportation Research Board (TRB) Annual Meeting*, Paper No. 14-0943, Washington D.C., United States, 2014.
32. Gates, T.J. and Noyce, D.A., Dilemma zone driver behavior as a function of vehicle type, time of day, and platooning. *Transportation Research Record*. 2010. 2149(1), pp.84-93.
33. Sun, J., Wang, Z., Yang, J. and Ouyang, J., Comparison of Dilemma Zone and Driver Behavior of Trucks and Passenger Cars at High-Speed Signalized Intersections. *Transportation Research Board (TRB) 94th Annual Meeting*, Paper No. 15-3723, Washington D.C., United States, 2015.
34. Yan, X., Radwan, E., Guo, D. and Richards, S., Impact of "Signal Ahead" pavement marking on driver behavior at signalized intersections. *Transportation Research Part F: Traffic Psychology and Behaviour*. 2009. 12(1), pp.50-67.
35. El-Shawarby, I., Rakha, H., Inman, V. and Davis, G., Evaluation of driver deceleration behavior at signalized intersections. *Transportation Research Record: Journal of the Transportation Research Board*. 2007. 2018(1), pp.29-35.
36. El-Shawarby, I., Abdel-Salam, A.S.G. and Rakha, H., Evaluation of Driver Perception–Reaction Time Under Rainy or Wet Roadway Conditions at Onset of Yellow Indication. *Transportation Research Record: Journal of the Transportation Research Board*. 2013. 2384(1), pp.18-24.
37. Caird, J.K., Chisholm, S.L., Edwards, C.J. and Creaser, J.I., The effect of yellow light onset time on older and younger drivers' perception response time (PRT) and intersection behavior. *Transportation research part F: traffic psychology and behavior*, 2007. 10(5), pp.383-396.
38. Awad, W., Abudayyeh, D., Al-Atrash, A., Jumaa, O., Shareef, A., and Ishtaiwe, M., Drivers' Behavior at Signalized Intersections. Proceedings of the Seventh Traffic Safety Conference, 12-13 May, Amman, Jordan, 2015.
39. Hussain, Q., Alhajyaseen, W., Brijs, K., Pirdavani, A., & Brijs, T., Improved Traffic Flow Efficiency During Yellow Interval at Signalized Intersections Using a Smart Countdown System. *IEEE Transactions on Intelligent Transportation Systems*, 2020.
40. Hussain, Q., Alhajyaseen, W. K., Brijs, K., Pirdavani, A., & Brijs, T., Innovative countermeasures for red light running prevention at signalized intersections: A driving simulator study. *Accident Analysis & Prevention*, 2020, 134, 105349.

41. Long, K., Liu, Y. and Han, L.D., Impact of countdown timer on driving maneuvers after the yellow onset at signalized intersections: An empirical study in Changsha, China. *Safety Science*, 2013. 54, pp.8-16.
42. Huey, S.B. and Ragland, D., Changes in driver behavior resulting from pedestrian countdown signals. Safe Transportation Research & Education Center, Institute of Transportation Studies, UC-Berkeley, 2007.
43. Palat, B. and Delhomme, P. A simulator study of factors influencing drivers' behavior at traffic lights. *Transportation research part F: traffic psychology and behaviour*, 2016. 37, pp.107-118.
44. Shen, J., Wang, W. Effects of flashing green on driver's stop/go decision at signalized intersection. *Jounal of Central South University*. 2015. Vol. 22, No. 2. pp. 771–778.
45. Swake, J., Jannat, M., Islam, M. and Hurwitz, D., Driver response to phase termination at signalized intersections: are driving simulator results valid. In *7th International Driving Symposium on Human Factors in Driving Assessment, Training, and Vehicle Design*, Bolton Landing, NY, 2013.
46. MAGIX Software. VEGAS Pro. 16. Video production, audio editing & disc authoring. Available at: https://www.vegascreativesoftware.com/us/sem/vegas-pro/
47. Gates, T., Savolainen, P. and Maria, H.U., Prediction of driver action at signalized intersections by using a nested logit model. *Transportation Research Record: Journal of the Transportation Research Board*. 2014. 2463, pp.10-15.
48. Tang, K., Xu, Y., Wang, P., Wang, F. Impacts of Flashing Green on Dilemma Zone Behavior at High-Speed Intersections: Empirical Study in China. *Journal of Transportation Engineering*. 2015. Vol. 14. No. 7.
49. Kocić, A., Čelar, N., Kajalić, J., & Stanković, S. Flashing green effects on traffic efficiency. *Put i saobraćaj*. 2020. 66(2). Pp. 27-31.
50. Gates, T.J., Noyce, D.A., Laracuente, L. and Nordheim, E.V., Analysis of driver behavior in dilemma zones at signalized intersections. *Transportation Research Record.* 2007. 2030(1), pp.29-39.