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DRIVER PERFORMANCE THROUGH THE YELLOW PHASE USING VIDEO CAMERAS 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, whether the vehicle position is in a platoon or not, presence of RLR cameras, green light flash devices, pedestrians, and pavement markings. A total of 2168 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, and 7% of the drivers committed RLR violations. The results showed that drivers were more likely to stop before the stop line through the yellow phase at locations with RLR cameras, green light flash devices, pavement markings, where pedestrians were present, and at a four-leg intersection. Chi-square tests indicated that all parameters had a significant impact on driver performance, except for the type of turning movement.

1. INTRODUCTION

In a signalized intersection, incorrect driver decisions through the yellow phase led to red-light running (RLR) violations or crashes, such as right-angle, left-turn, and rear-end crashes. RLR can be defined as follows: "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 occur because of the presence of the drivers in "dilemma zones" through the yellow phase. Based on the 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 greater than the maximum crossing (clearance) distance. At the zone between the minimum and the 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.

The dilemma zone can be classified into two types: type I and type II. A type I dilemma zone is 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]. This occurs because of incorrect geometric design and proper traffic signal timing [4, 5]. A type II dilemma zone or indecisive zone 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]. This occurs because of the driver's decision during the yellow phase. Therefore, the dilemma zone should be studied to eliminate it as best as possible and to improve traffic security at signalized intersections.

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 a speed slower than the speed limit, an option zone will be created, while when the driver is traveling at a speed higher than the speed limit, a dilemma zone will be created [8].

Globally, traffic crashes are ranked as the 9th most common 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 have been intersection related [11]. Also, more than 6 million reported accidents related to intersection crashes were reported, of which more than 15,000 were fatal crashes [10]. Moreover, traffic crashes at signalized intersections because of red-light running lead to 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 and 16,246 injuries, and the cost was estimated to be approximately 308 million Jordan dinars [13]. There was a total of 155 traffic crashes related to RLR violations in 2018 [14]. These statistics show a high number of crashes and indicate that traffic crashes are a major problem in Jordan and all countries worldwide. This research will shed light on 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 “stop/go decision” and critical distance to the 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 studied the influencing parameters on driver performance in urban, suburban, and rural areas in Australia, USA, Europe, and Asia, such as vehicle distance to the stop line at the start of the yellow phase, vehicle type, vehicle position, intersection type, presence of RLR cameras, presence of green light flash devices, presence of pedestrians, presence of countdown timers, traffic signal timing, demographic characteristics of the driver such as age and gender, and using cell phones while driving.

It was found that vehicle distance to the stop line, vehicle type, vehicle speed, green light flash devices, using cell phones while driving, and demographic characteristics of the driver including age and gender had a significant impact on the driver performance through the yellow phase [7, 16 – 29]. The results of Bao et al. [23] showed that drivers were more likely to reach intersections with green light flash devices. Also, Savolainen et al. [22] found that the presence of green light flash devices increased the probability that drivers would stop at 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 more likely to stop at 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 occurrence of RLR. Likewise, Sun et al. [33] indicated that vehicle type significantly impacted the distribution of type 1 and type 2 dilemma zones. Yan et al. [34] showed that pavement markings reduced the probability of risky intersection crossings and conservative decisions through the yellow phase. Also, Gates et al. [31] indicated that drivers at intersections with short yellow phases were more likely to stop, while drivers at intersections with long cycle length and red clearance intervals were more likely to go through the yellow phase. El-Shawarby et al. [35, 36] and Rakha et al. [17] reported that time to the intersection and roadway grade had a significant impact on the driver perception reaction time, while driver age had no effect. 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. The results showed that the measured perception-reaction time was not affected by driver age, while time to the stop line had a significant effect on the perception-reaction time. Moreover, younger drivers showed significantly higher acceleration and deceleration rates than older drivers. Finally, older drivers were less likely to pass the intersection than drivers in 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] reported that the probability of crossing decision during the yellow phase increased under the green LED dynamic light (G-LED) condition compared with a controlled condition, which means that the G-LED condition improves the efficiency of signalized intersections. Also, the G-LED condition enables the driver to make a prudent and safe decision to cross. 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 drivers making the decision to stop at intersections without a countdown timer device was significantly higher than at intersections without countdown timer devices. Also, Long, Liu, and Han [41] studied the impact of countdown timer on driving maneuvers during the yellow phase at four urban signalized intersections in Changsha city, China. The 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. The results showed that the total number of vehicles that stop or enter the intersection after the green phase signal without a pedestrian countdown timer was higher than that at the intersection with a 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, wherein, 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. The 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 the driver behavior model of the type 2 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 have focused on investigating driver behavior during the yellow phase and the influencing 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 received full attention in traffic and safety research. This study used video cameras to record traffic signal indications, driver actions, and influencing 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, provides the researcher with an opportunity to review all the gathered information and provide accurate results. Besides, no previous research, nationally or globally, has 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, green light flash devices, presence of pedestrians, pavement marking conditions, 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, and 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 strategies to reduce aggressive driver performance through the yellow phase and increase safety at urban signalized intersections.

4. METHODOLOGY

Eight urban signalized intersections were selected in Irbid City, Jordan. Four intersections had RLR cameras, and four different intersections did not have RLR cameras. In addition to the intersection type, further field data were collected to cover several characteristics such as studied approach, posted speed limit (km/hr), number of lanes on the target way (lane), number of cross lanes by the target way (lane), intersection width (meter), 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 green light flash devices (yes, no), presence of pedestrians (low pedestrian activity, medium to high pedestrian activity), and pavement marking conditions 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 Table 1.

Table 1

Criteria of Site Selection

Check	Criteria
Channelization	Island
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. A 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 driver performance through the yellow phase. A 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 studied 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. Tables 2 and 3 present the summary of the data collected.

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 last vehicle in the queue and an oncoming vehicle is two seconds or less, the vehicle position was recorded in the platoon.

Otherwise, the vehicle position was not recorded in the platoon. This was extracted from a video camera based on visualization.

4. Vehicle lane position, headed to through movement, left, or U-turn, was extracted from a 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 extracted from a video camera based on visualization.

Table 2

Intersection Characteristics

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.

Table 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 Markings	Yes	Yes	Yes	Yes	No	No	Yes	No
Green Light Flash	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Pedestrian activity	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

A chi-square test was used to examine associations between categorical variables. The null hypothesis of the test is that there is no relationship between 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 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.

5. RESULTS

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

Fig. 1. Screenshot of an intersection (T3) video

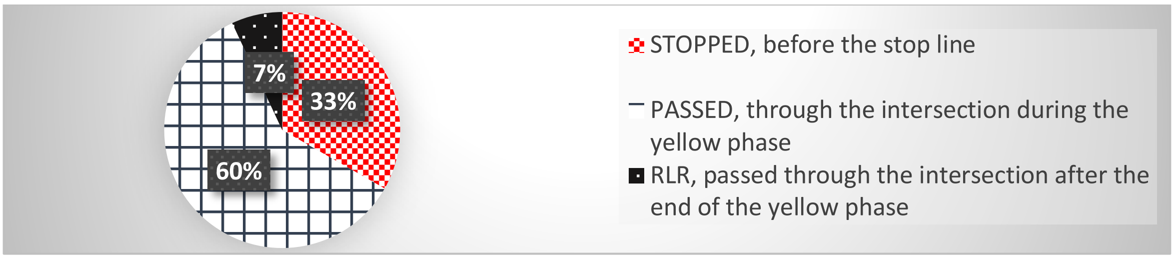

Fig. 2. Distribution of Observations at all Studied Intersections

The presence of RLR cameras, presence of green light flash devices, presence of pedestrians, pavement marking conditions, intersection type, vehicle type, turning movement type, and vehicle position were considered as parameters expected to affect driver performance through the yellow phase. Data analysis results showed that drivers were more likely to stop before the stop line through the yellow phase at locations with RLR cameras, with a green light flash device, in the presence of a high number of pedestrians, at locations with pavement markings, and at four-leg intersections. Also, vehicles in the platoon position had a higher percentage of pass action, 69.8%, than vehicles not in the platoon position, 46.6%. Moreover, vans showed the highest percentage of pass actions among all types of vehicles, 77%, and taxis showed the lowest percentage of pass actions at 54.5%. On the other hand, trucks and pickups had similar percentages of pass actions of 64% and 54.9%, respectively. Table 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 categorical variables, where the null and alternative hypotheses are as follows:

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

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

6. DISCUSSION

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

6.1. Presence of RLR Cameras

The results showed that 33% of the observations were recorded at signalized intersections with RLR cameras and 67% of the observations were recorded at signalized intersections without RLR cameras. Signalized intersections with RLR cameras had 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 the ones with RLR cameras (42.2%).

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

6.2. Presence of Green Light Flash Devices

A total of 68% of the observations were recorded at signalized intersections with green light flash devices and 32% of the observations were recorded at signalized intersections without green light flash devices. Data analysis results showed that signalized intersections without green light flash devices 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 green light flash devices (52.3%, 5.6%, and 42.1%, respectively). This could be linked to the presence of green light flash devices, which enable drivers to make a decision during the transition phase and reduce the frequency of RLR violations since they have prior understanding that the yellow period will start after the green period ends. Pearson's chi-squared test shown a significant difference at the 95% confidence interval between signalized intersections with and without green light flash devices ($x^2 = 165.055$, DF = 2, $p = 0.000<0.05$). The null hypothesis that stated that signalized intersections with and without green light flash devices are independent variables is rejected. These results of the presence of green light flash devices are in agreement with those of Gates et al. [47] and Savolainen et al. [22], who concluded that the presence of green light flash devices had a significant impact on driver behavior, with an increase in the probability of early stopping. However, this result is not in agreement with the results of Bao et al. [23], who reported that drivers were more likely to pass the intersections through the yellow phase at signalized intersections with green light flash devices. In summary, several studies concluded that use of green light flash devices 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.

6.3. Presence of Pedestrians

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

Pearson's chi-squared test showed a significant difference at the 95% confidence interval between signalized intersections with a low or an intermediate to high level of pedestrian activities ($x^2 = 33.046$, DF = 2, $p=0.000 <0.05$). The null hypothesis that stated that the signalized intersections with low, medium to high number of pedestrians are independent variables is rejected. These results are in agreement with those of Gates et al. [50], who stated that the presence of pedestrians had a significant impact on driver performance through the yellow phase at urban and suburban signalized intersections.

This means that drivers were more likely to pass through locations with a low number of pedestrians. Proper signal settings for both vehicles and pedestrians, along with suitable enforcement, can improve safety at urban signalized intersections.

Table 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 Green Light Flash 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 Pedestrians	**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 Conditions	**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%**

Table 5

All results of the chi-square test for the studied influencing factors

Influencing factors		Tests (Chi-Square)		
		value	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
Green Light Flash Device	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 Conditions	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**			

Table 6

Phi and Cramer's test results for all the 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
Green Light Flash Device	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 Conditions	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

6.4. Pavement Marking Conditions

Five signalized intersections with pavement markings and three signalized intersections without pavement markings were included in this research. In all, 41% of the observations were recorded at signalized intersections with pavement markings, and 59% of the observations were recorded at signalized intersections without pavement markings. Data analysis results showed that signalized intersections without pavement markings show a higher percentage of pass action (70.6%) and RLR violations (9.4%) than signalized intersections with pavement markings (44.2% and 3.5%, respectively). This is because the presence of pavement markings warns the driver, and the presence of pavement markings depends on the presence of RLR cameras at most signalized intersections.

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

6.5. Intersection Type

Three- 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 refers to the number of conflict movements from different directions at three-leg intersections, which is lower than four-leg intersections, causing the pass and RLR violations more easily than four legs signalized intersections.

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

6.6. Vehicle Type

Vehicle types were classified into five major categories, including passenger cars, taxis, vans, pickups, trucks, and buses. Nearly 71% of the vehicles were passenger cars, 11% were taxies, 5% were vans, 4% were pickups, 6% were trucks, and only 3% were buses. Data analysis results showed that vans had the highest percentage of pass action (77%), while taxis had the lowest percentage of pass action (54.5%). Trucks and pickups had similar percentages of pass action (64% and 65.9%, respectively).

The Pearson chi-square test showed a significant difference at the 95% confidence interval between different types of vehicles ($x^2 = 19.645$, df = 10, $p = 0.033 < 0.05$). The null hypothesis that stated that driver behaviors according to different types of vehicles are independent variables is rejected. These results are in agreement with those of Alex et al. [16], Gates and Noyce [32], and Gates et al. [50], who concluded that vehicle type had a significant impact on driver performance through the yellow phase.

6.7. Turning Movement Type

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

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

6.8. 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 a platoon showed a higher percentage of RLR violations (9.1%) than vehicles in a platoon (5.4%). Also, vehicles in a platoon showed a higher percentage of pass action (69.8%) than vehicles not in a platoon (46.6%). That is referred to the following drivers' actions (vehicles in the queue), which are affected by leading-drivers' decisions (at the front of the queue).

Pearson's chi-squared test showed a significant difference at the 95% confidence interval between different types of vehicle positions (x^2 = 118.592, DF=10, p=0.000<0.05). The null hypothesis that stated that vehicle position at signalized intersections is an independent variable is rejected. This result is in agreement with those of Bao et al. [23], who concluded that vehicle position had a significant 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 subsequent driver action. Moreover, this result is not in agreement with that of Gates and Noyce [32], who concluded that driver performance through the yellow phase was not affected by whether the vehicle was 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. These 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 activities of drivers like eating, smoking, and using cell phones. Also, this study investigated driver behavior at peak periods during 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 overcome this limitation. Future research should cover more signalized intersections during off-peak periods and in suburban and rural areas.

7. CONCLUSIONS

The aim of this article was to examine the influencing parameters on driver performance through the yellow phase. Eight urban signalized intersections with and without RLR cameras were selected. A video camera was used and placed for two hours at a sufficient height upstream of an intersection to record traffic signal indications, driver actions, and influencing parameters on driver behavior. A total of 2168 driver behavioral observations were extracted from data collection. Only 33.3% of the observations showed that drivers stopped before the stop line, 59% of the observations showed that drivers passed the intersection through the yellow phase, while 7% of the observations showed that drivers passed the intersections after the end of the yellow phase (RLR violations).

Data analysis results showed that drivers were more likely to stop before the stop line through the yellow phase at locations with RLR cameras, with green light flash devices, with high number of pedestrians, with pavement markings, and at four-leg intersections. Vans showed the highest percentage of pass action among all types of vehicles, 77%, while taxis had the lowest percentage of pass action, 54.5%. In comparison, trucks and pickups had similar percentages of pass action of 64% and 54.9 %, respectively. Through, left, and U-turn movements had similar percentages of pass action of 58.4%, 61.3%, and 57.8%, respectively. However, through movements were found to have the highest RLR violation rate. Also, vehicles in a platoon had a higher percentage of pass action, 69.8%, than vehicles not in a platoon, 46.6%. Chi-square tests showed that the presence of RLR cameras, presence of green light flash devices, presence of pedestrians, pavement marking conditions, intersection types, vehicle types, and vehicle positions had a significant impact on driver performance through the yellow phase but turning movement type did not.

To improve the safety at urban signalized intersections, several strategies can be recommended based on this study and previous research, as follows:

1. RLR cameras must be installed at all traffic intersections to enable and improve law enforcement.
2. Infrastructure for pedestrians to increase safety, such as crosswalks, bridges, tunnels, sidewalks with sufficient width, and intermediate islands.
3. There should be stricter action against drivers who violate the red-light phase.
4. Traffic signal timing needs to be improved according to the traffic volume demands, geometric characteristics of intersections, and traffic conditions.
5. Training and educational courses focusing on safety awareness and driving ethics must be reviewed and reconsidered by the authorities for new drivers, as well as for existing drivers. These measures improve the commitment and awareness of drivers when crossing 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, and presence of passengers in the vehicle or not), and activities performed by drivers like eating, smoking, and using cell phones. Future research should also cover more signalized intersections during peak and off-peak periods in urban, suburban, and rural areas in different cities around the world.

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