The Noncompliance Behavior at Signalized Intersection in the Eastern Province of Saudi Arabia

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**Abstract.** In Saudi Arabia, drivers that run red lights are the leading causes of crashes every year constituting 21% of the total crashes in urban area. This study primarily aims to determine the type and frequency of violation at signalized intersections in the Saudi Arabian Eastern Province. Accordingly, this study focused on twelve intersections to examine the type of violations and utilized the approach volume and land use to study the relationships between traffic violations and geometric characteristics. On the basis of the analysis of data obtained, during an hour, the number of drivers that crossed the intersection at yellow was 23.65, and those that cross at red numbered 10.58, those that start on red numbered 23.63, and those that turn right on red without stopping numbered 24.32. Finally, those that turn right on red without stopping numbered 34.6 and additionally, the number of drivers that crossed the street even after the red light has been on for 5 seconds was 1.31 per hour. This study recommends to continue use red light running camera system, which is one of the automated enforcement that can be effective to reduce red light runners at signalized intersections to enhance compliance level of drivers with traffic signals at intersections.

**Keywords:** Red light running, Enforcement, Risky driving, Driver behavior.

**List of Abbreviations**

TCD = Traffic Control Device
RLCs = Red Light Cameras
AADT = Annual Average Daily Traffic
NSOYVF = Not stopping on yellow violation frequency
NSORVF = Not Stopping on Red violation frequency
SORVF = Starting on red violation frequency
RTRWSVF = Right turn on red with stop violation frequency
RTRWOS = Right turn on red without stopping frequency
TOTVIOLF = Total number of violations frequency
NSOY = Not Stopping on Yellow
NSOR = Not Stopping on Red
NSOR5SEC = Not Stopping on Red after 5sec
SOR = Starting on Red
RORWS = Right Turn on Red With Stop
RORWS = Right Turn on Red Without Stop
ROR = Right Turn on Red
TOTVIOL = Total Violation
HVOL-LFT = hourly volume left
HVOL-ST = hourly volume straight
HVOL-TOT = hourly volume total
HFREECH = hourly free choice
HVOL-RGT = hourly volume right
GTIME = green time
CYCTIME = cycle time
RTIME = red time
STDD-DEV = standard deviation
MD-WIDTH = median width
STR-TYP = street type
LN-MARK = lane marking
PED-CRSS = pedestrian crossing
EXLFT-LN = existence of left turn lane
EXRDT-LN = existence of right turn lane
MD-EXIST = existence of median
SIGHT = sight distance
LS-MEANS = least square means

1. Introduction

The increase of motor vehicle in Saudi Arabia is unprecedented. Back in year 1970, only 100,000 vehicles were registered, but by year 2000, the total number of vehicles grew up to 1.8 billion[1].

As days pass, every country around the globe experience traffic accidents that leave behind human loss and destruction of properties[2-3]. As a result, loss of life and limb, as well as the socio-economic cost are experiencing a constant increase. In this regard, traffic accidents are not confined to loss of life but also cause irreparable damage to those that have been affected. Millions of individuals lose their lives or are seriously injured in motor vehicle accidents[4-6].

In the context of Saudi Arabia, over 5,982 people died and 34,441 individuals had serious disabling injuries from traffic accidents in year 2006 alone[7]. In fact, traffic accidents have been noted to be the major cause of death in Saudi Arabia, with around 10% of total deaths attributed to it[8-10]. In addition, a total of 589,258 traffic accidents occurred in 2012, an increase of approximately 8% compared with 2011. Moreover, the number of fatalities resulted from traffic accidents was 7,638, an increase of nearly 7% compared with 2011[11].

Therefore, the disregard of traffic control devices (TCDs) among drivers is becoming an increasing concern for traffic engineering and road safety sector. This is particularly dire as noncompliance among drivers with the TCDs, particularly regulatory control devices have shown an increase over the past years, in developing countries, including Saudi Arabia[12]. Such noncompliance with the traffic rules and regulations bring about an increase in road accidents[13]. According to Koushki and Ghadeer[12], excessive speed and noncompliance with traffic signals are serious causes of accidents at intersections. Red light running at intersections is the major cause for accidents in in Riyadh, Saudi Arabia[14].

In relation to the above, Gordon and Robertson[15] concluded that factors may contribute to driver noncompliance and they include highway geometrics and traffic operation characteristics (volume, type of regulatory control and speed). Moreover, drivers’ responses to stopping at yellow light at traffic signals in Norwich (urban area), and Takeley and Chelmsford (rural areas) in the UK, indicated that 3% of the drivers crossed the stop sign over 3 seconds after the onset of amber in the first area, 5% in the second and 12% in the third.

Al-Atawi[13] studied the characteristics of crossing red light violations in urban areas in Tabuk. It reveals that different factors such as speed, road width, and speed on cross road, and width of cross road, significantly affects such violation. Road width, red time, and speed appear to be the most important ones.

Haleem and Abdel-Atyi[16] examined the factors associated with traffic crash injury severity at unsignalized intersections in Florida using three approached: Ordered probit model, binary probit model, and nested logit model. It was found that the traffic volume on the major approach, the number of through lanes on the minor approach (surrogate measure for traffic volume), the upstream and downstream distance to the nearest signalized intersection, the left and right shoulder width, the number of left turn movements on the minor approach, and the number of right and left turn lanes on the major approach were the significant variables affecting crash severity at unsignalized intersections.
The Noncompliance Behavior at Signalized Intersection in the Eastern Province of Saudi Arabia

In the U.S., Richard et al. [17] (1999) examined the effect of setting up traffic cameras in Oxnard, CA. The study chose nine camera sites based on the history of police reported accidents involving crossing of red lights. Findings showed that such violation decreased from 13.2 to 7.7 per 10,000 vehicles following the implementation of the project. However, the overall violation rate in the administered sites in the city of Santa Barbara, CA. remained the same (7 per 10,000 vehicles)—these sites were chosen based on safe and unobtrusive observation accorded and the access to data, rather than site history.

In Saudi Arabia, driver violations of traffic control devices earliest documentation dates back to 1984 [7]. The analysis of these statistics revealed that the number of traffic violations around the kingdom showed an increase of 260% over the span of 6 years (1984-1989) and the number of reported road accidents increased by 23.

According to the statistics published in the traffic department in 2004, there were 261,211 violations involving crossing of red light in 2003, constituting 5% of the total number of violations in Saudi Arabia. Such violations caused 15% of accidents—a percentage that was reduced from 21% (1973-1985) [18].

In a particular perspective, 16 intersections were examined by Koushki and Ghadeer [12] in Riyadh and Buraidah and they found that the highest violation rate occurred at night, followed by off-peak hours and morning peak hours. During off-peak and night hours, the accidents were attributed to traffic volumes, tolerant enforcement, and driver exhaustion from a long day of work.

Similarly, in Virginia, Maryland and District of Columbia, Gordon and Robertson [15] investigated driver noncompliance with traffic signals at 12 intersections. The authors revealed that drivers were under different operational conditions at the traffic light intersections in peak and off-peak hours, daytime and nighttime hours. Most violations occurred on low AADT (Annual Average Daily Traffic) volume intersection channels. This was supported by the results reported by Hall and Margarita [19] who concluded that accident rates are quite significant at night, when the flows of traffic are low. This was attributed to the sleepy or impaired vision of drivers and the difficulties of driving in low light.

In 2010, Saudi Arabia launched the automated traffic monitoring and speed enforcement system and called SAHER. It uses red light cameras to enforce traffic laws at signalized intersections. The outcomes of Saher system are encouraging. It has reduced the severity of traffic accident injuries by 20 percent and mortality rate by 37.8 percent in Riyadh after the implementation of Saher system [20].

This paper has been extracted from the data collected and supervised by the author and others [2-21]. Considering the above issue, this study primarily aims to determine the type and frequency of violation at traffic light intersections in the Eastern Province of Saudi Arabia and accordingly, the following are the study objectives:

1- To examine the type of violations and their frequency at the traffic light intersections.

2- To examine the relationships between traffic violations and geometric characteristics, approach volume and land use.

3- To provide recommendations in order to improve safety driving skills based on the findings of the above investigations.

2. Definition of Violation Type

Based on the reviewed literature and field observations and considering the research hypotheses, six violation types are defined at
signalized intersections and they are as follows:

1- Not stopping on yellow (NSOYVF) violation frequency – this indicates the number of vehicles speeding to cross the intersection even after the onset of the yellow light, rather than slowing down and waiting for the next green phase.

2- Not Stopping on Red (NSORVF) violation frequency – this indicates the number of vehicles turning left and entering the intersection past the curb line even after the red signal is displayed.

3- Starting on red (SORVF) violation frequency – this indicates the number of vehicles that start to move prior to the appearance of the green light.

4- Right turn on red with stop (RTRWSVF) violation frequency – this indicates the number of vehicles that make a right turn on red with stop where such a turn is not permitted.

5- Right turn on red without stopping (RTRWOS) violation frequency – this indicates the number of vehicles that make a right turn on red without a short stop on a turn that is permitted.

6- Total number of violations (TOTVIOLF) frequency – this indicates the total sum of the above 5 violations.

The rates of violations are calculated by dividing the number of violations for every 100 vehicles of the corresponding volume of traffic.

3. Study Duration

Glauz and Migletz’s [22] (1980) equation is used to determine the required duration (NT) of the present study:

\[ NT = \left[ 100 \cdot \frac{Z}{PC} \right]^2 \cdot \frac{\sigma^2}{mean^2} \]

Where:

- \( NT \) = Number of hours that the traffic must be observed
- \( Z \) = A constant corresponding to desired level of confidence (i.e. 90%)
- \( PC \) = Permitted error in the estimate of mean conflict rate
- \( \sigma^2 \) = Variance of the noncompliance rate (expected)
- \( mean \) = Hourly mean value of red light violations.

This study requires the determination of the hourly mean and hourly variance values of non-compliance. In Koushki and Ghadeer’s study [12] about driver noncompliance with traffic signals in Riyadh and Buraidah, the average mean per hour was 13.5 violations, with standard deviation of 3.9 violations for speeding on yellow. This violation indicated lower frequencies compared to going through red.

Mean = 13.5 violation/hour
Standard Deviation = 3.9 violation/hour
\( Z = 1.96 \) (for \( \alpha = 0.05 \))
\( P = 50\% \)

\[ NT = \left( 100 \cdot \frac{1.96}{50} \right)^2 \cdot \frac{3.9^2}{13.5^2} \]

\[ NT = 1.28 \text{ hours} \]

The confidence was increased by studying for one and a half hour at the chosen area (approach).

3.1 Number of Intersection Approaches

The size of the sample was determined with the formula taken from the Manual of Transportation Engineering Studies (1994, p. 229) [23].

\[ n = \frac{Z^2 \sigma^2}{E^2} \]
Where:

\[ n = \text{Number of approaches}. \]
\[ Z_{0.025}/2 = \text{normal random variable at 95% confidence level}. \]
\[ \sigma^2 = \text{expected variance of the noncompliance rate}. \]
\[ E = \text{expected error}. \]

On the basis of the study by Koushki and Ghadeer [12] in the context of Riyadh and Buraidah, the mean and standard deviation for speeding on yellow violation were noted to be 3.35 and 1.95 respectively per hour, per approach. Therefore, the size of the sample so as to provide a margin of error that does not exceed + 1.68 (50% of mean);

Therefore:

\[ n = 1.96^2 \times (1.95)^2 / (1.65)^2 \]
\[ n = 5.4 \text{ approaches} \approx 6 \text{ approaches}. \]

4. Experimental Design

This study conducted the violation counts and interviews in Khobar, Dammam and Al-Qatif using an experimental design to examine the time effect (peak, off peak and evening) location (CBD and fringe area) and the intersection geometry that covers left turn lanes and number of lanes (1, 2, 3 or more). Nevertheless, it was impossible to obtain sufficient approaches with 3 or more lanes, without left-turn lanes. Therefore, the experimental design was modified and the line corresponding to these approaches were dropped as shown in Table 1. Each cell contained at least 6 approaches as per the sample size requirement calculated above.

Random selections were intersections were made from a list of intersections in five Eastern Province areas including Al-Augrabia, Khobar, Dammam, Thuqba and Qatif. Approaches were obtained for each area (see Table 1), with each cell containing at least 6 approaches per sample size requirement as previously calculated.

Table 1. Experimental design of violation counts.

<table>
<thead>
<tr>
<th>Approach Geometry</th>
<th>Number of Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Left Lane</td>
<td></td>
</tr>
<tr>
<td>3 or more lanes</td>
<td>10</td>
</tr>
<tr>
<td>1 or 2 lanes</td>
<td>6</td>
</tr>
<tr>
<td>Without Left Lane</td>
<td></td>
</tr>
<tr>
<td>1 or 2 lanes</td>
<td>8</td>
</tr>
</tbody>
</table>

5. Methodology of the Study

5.1 Site Selection and Characteristics

A total of twelve intersections were chosen, as mentioned, from the Eastern Province, including the areas of Khobar, Dammam and Qatif area, with the major consideration being that the intersections should have fundamental design elements that were similar to intersections in other areas of the Kingdom.

In sum, the experimental design involved the selection of intersections based on; area type (CBD or fringe), number of approaches (four), number of approach lanes, geometric approaches (with or without left turn lane), and traffic volume. Accordingly, a survey was conducted around the three areas and an inventory of 60 intersections was carried out. From the total possible locations, twelve intersections were chosen based on the above-mentioned conditions. The locations were selected to cover the whole area, with six intersections located in Khobar, four in Dammam and two in Qatif.

5.2 Data Collection

A 5-member team was assembled to collect data concerning physical and operational characteristics, traffic volume, traffic violations and approach speed. The entire intersections were operating in fixed time signal controllers, and each had 4 stages. Data was collected from Saturday to
Wednesday, because the traffic pattern during weekdays varies from the weekends and thus, the experimental design excluded weekends. Observation was made from 1:30 noon to 7:30 in the evening and data collected for every intersection included; traffic volume count (left, right and through), traffic violation count (six types), speed measurement, signal timings (green time, yellow time, red time and signal cycle length), operational and physical checklist of intersection, rough sketch of intersection, and measurement of approach width and median width.

Because the time under which the compliance observations are conducted can influence the outcomes, this study was conducted in good weather, under normal conditions, with no circumstances affecting the outcome. During the observation period, dry pavement conditions and fair temperatures prevailed.

The team collected traffic volume and traffic violations data for 2-hour period in the off-peak hours from 1:30 to 3:30 PM, peak hours from 3:30 to 5:30 PM and evenings from 5:30 to 7:30 PM, spending 6 hours for every intersection. In addition, for every intersection, the traffic volume and violations were noted on a rotation of 15-minute intervals, for every approach for 6 hours. In other words, 15 minutes sample volume and violations were provided per hour per approach. For each of the above span of period, there are half hour readings, with hourly volumes noted by expanding the half hour sample counts in each approach.

6. Analysis of Traffic Violations

6.1 Results

The study of traffic violation was statistically analyzed through the use of correlation statistics, particularly Anova, Ancova and regression, F-test and t-test. The traffic violations were also compared to other studies. The analysis process called for data coding in the first phase.

Additionally, the different violation categories were transformed into rates for comparison purposes. Such transformation was brought about by dividing each category by its respective volume. For results clarification, the comparisons were plotted in bar charts (see Fig. 1 and 2). Figure 1 shows that a total of 118 vehicles violated the red and yellow signals under an average of an hour per approach – a frequency that is considered as high.

The total violation in light of specific violations can be broken down as follows; 23.65 drivers violated the intersection at yellow, 10.58 crossed at the red light, 23.63 started on red, 24.32 turned on the red light with stopping, and 34.6 turned right on red without stopping, for every hour and every approach. The top violation among the ones mentioned is crossing on red even after the red light is on for 5 seconds (HNSR5SEC) and it had a frequency of 1.31.

The rate of violation based on the type of violation is presented in Fig. 2. Based on the figure, the highest rate of violation is for the right turn on red (ROR), a combination of right turn on red with stop (HRORWS) and right turn on red without stop (HRORWOS). Meanwhile, the highest violation rate based on volume was found to be starting on red (HSOR), followed by not stopping on yellow (HNSY), not stopping on red (HNSR) – with the not stopping on red after the red light is on for 5 seconds (HNSR5SEC) (to most dangerous of violations) obtaining the lowest violation rate compared to others.

The potential relationship between the volume signal and speed variables and the violation variables was determined through the use of Pearson’s Correlation Analyses, using SAS (1990). The correlation analysis results are presented in Table 2 and from the table, it
is evident that the variables are significantly correlated with violation variables at the significance level of 5%.

More specifically, the same variables affected not stopping on yellow (HNSY) and not stopping on red (HNSR), and they are hourly volume left (HVOL-LFT), hourly volume straight (HVOL-ST), hourly volume total (HVOL-TOT) and hourly free choice (HFREECH). However, the two violation variables were not found to be correlated with hourly volume right (HVOL-RGT). With regards to signal timing variables, both variables (HNSY and HNSR) were found to be affected by the variables, green time (GTIME) and cycle time (CYCTIME) but not red time (RTIME).

Moving on to speed variables, both variables (HNSY and HNSR) were found to be positively related with all speed variables of MEAN, STDD-DEV, V15THPER, V85THPER. Meanwhile, although HNSR5SEC violation was found to be affected by the volume and signal variables that did those of HNSR and HNSY, it was not affected by any of the speed variables, with the exception of MD-WIDTH.

For the violation of starting on red (HSOR), it was found to be affected by all volume, signal and speed variables, with the exception of standard deviation (STDD-DEV) and it was found to have a weak correlation with median width (MD-WIDTH). Contrastingly, HRORWS was found to be only affected by hourly volume (HVOL-RGT), which is a reasonable outcome as only right turning vehicles can violate it. Also, HRORWS and ROR were significantly and positively correlated with HVOL-RGT and HVOL-TOT. Because HVOL-TOT is the sum of HVOL-LFT, HVOL-RGT, HVOL-ST, it is worth noting that HRORWOS and ROR were positively correlated with HVOL-RGT but weakly so with HVOL-TOT. Moreover, HRORWOS was affected by free choice (HFREECH). Finally, total violation was positively and significantly correlated with the three classes, and was affected by the entire volume variables, all signal timing variables as well as all speed variables, with the exception of STDD-DEV and V85THPER.
7. Analysis of Covariance (ANCOVA) of Explanatory Variables

This study conducted ANCOVA to determine the effects of explanatory variables on violation frequencies. One-way analysis of variance was performed involving significant covariates – the covariates were obtained through stepwise regression analysis (see Table 3 footnote). The variables that were found to have a significant effect on the violations are presented in Table 3.

Table 3 shows that time, area, land-use and street type (STR-TYP) did not have significant effects on any of the violation,
while location, lane marking (LN-MARK) and pedestrian crossing (PED-CRSS) only affected on violation each. Also, both location and pedestrian crossing affected starting on red (HSOR), and lane marking affected HRORWS.

Moving on to geometric variables, the results showed that EXLFT-LN affected HNSR, HSOR and HRORWOS, whereas EXRDT-LN affected right turn on red violations (HRORWS and HRORWOS) but not starting on red (HSOR) violation for some non-obvious reasons. In addition, existence of median (MD-EXIST) were revealed to affect HSOR, HRORWOS and ROR violations, with ROR being the sum of HRORWS and HRORWOS violations. Furthermore, sight distance (SIGHT) was found to affect right turn on red with stop (HRORWS) as well as right turn on red (ROR).

7.1 Least Square Means (LS-MEANS) of Significant Categorical Variables

In order to obtain a clear overview of the relationship between categorical variables and the frequencies of violation, the least square means (LS-MEANS) of the variables were obtained with the help of the SAS package. The least square means refer to the means obtained following the adjustment of the covariates effects and they are presented in Table 4.

Table 4 shows that the median minimizes the violations of right turn on red without stop (HRORWOS) as well as total right turn on red (ROR). This may be attributed to the fact that the median exists on major intersections, where people drive with more caution. The results also show that the existence of left turn lane (EXLFT-LN) minimizes almost the entire violation frequencies with the exception of HRORWS, where it didn’t have any effect on, and HSOR, where it maximizes. Due to the minimal danger in HSOR violation in comparison to other types of violation, it can be stated that the existence of left turn lane increases the compliance at signalized intersections.

Moreover, existence of right turn lane minimizes both starting on red (HSOR) and right turn on red with stop violation (HRORWS) but maximizes the right turn on red without stop violation. This may be attributed to the fact that the right turn lane facilitates making an easy right turn. Hence, the overall safety benefit of existence of right turn lane becomes questionable.

Furthermore, while the number of lanes provide inconsistent results, when there is a single lane on an approach, the violation frequency is greater for HNSY, HNSR and HSOR in comparison to when there are two or three lanes on approach. This may be related to the one lane approaches location at fringe areas, and as such, at these areas traffic volume is minimal and so is enforcement. With the increase in thru lane, starting on red (HSOR) violation also increases because in major intersections, there are several number of thru lanes and the volume is more, which leads to longer signal cycle length and eventually heightened delay. Such delays instigate impatient drivers to start on red. In the case of major intersections, the compliance of red signal may therefore be increased by lessening the delays via adjusting the length of the signal cycle.

Both the existence of lane marking (LN_MARK) and good sight distance (SIGHT) leads to reduced right turn on red without stop violation. The latter also reduces the total right turn (ROR) on red. Therefore, it may be concluded that the existence of lane marking and sight distance improvement urges increased compliance at signalized intersection and as such, both are advantageous.
Furthermore, the Pedestrian crossing (PED-CROSS) decreases the violation of starting on red and this is a reasonable outcome as the width of the pedestrian crossing stops the drivers from crossing the line any further. Pedestrian crossing reduces the starting on red violation at intersections and as such it is beneficial to be present at intersections to encourage compliance behavior.

7.2 Comparison with Other Studies

This study, which is focused on the Eastern Province, is compared with the study conducted by Koushki and Ghadeer[12], conducted in the central city of Riyadh, and the study conducted by Gordon and Robertson[15] in the U.S. The first prior study was carried out in May 1990, while the second one was carried out in July 1986.

Table 5 presents the statistics comparing the studies based on the frequencies of violations for not stopping on red and right turn on red. Figures 3 and 4 illustrate the mean violation frequencies for the two types of violations. It is evident from Fig. 3 that the Eastern Province obtained the highest mean frequency of not stopping on red violation, followed by Riyadh and Buraidah and lastly, the U.S. More specifically, the mean frequency of Eastern Province is 8 times and that of Riyadh is 6 times than that of the U.S. The values are significantly high, indicating the poor situation in Saudi Arabia when it comes to non-compliance behavior at signalized intersections.

Moving on to the mean violation frequencies of right turn on red for the three cases (Riyadh, Eastern Province and U.S.), Fig. 4 shows that Riyadh obtained the highest right turn on red violation frequency, followed closely by Eastern Province. The U.S. frequency values lags behind those of the Saudi ones.

The comparison between the violation rates in the three studies are summarized and provided in Table 6. From the table, the Eastern Province obtained the highest rate of not stopping on red (HNSR) violation, with Riyadh and Buraidah and U.S. following suit. More specifically, on average, drivers in the Eastern Province do not stop on red 1.55 out of 100, drivers in Riyadh do not stop on red 1.24 out of 100, and drivers in the U.S. do not stop on red 0.41 out of 100, the last of which is around 4 times less in comparison to the first one.

As for the right turn on red violation, the rate is greatest in Riyadh, with the Eastern Province and the U.S. cases following suit. The last case for violation of right turn on red is quite low. Furthermore, by dividing the right turn on red violation with relevant volume of right turn only for the Eastern Province, it was found that 60% of the drivers violate the red signal when making the right turn. In comparison to the total violation rate at signalized intersections, Riyadh and the Eastern Province are almost at par, followed by Buraidah and the U.S. It can thus be concluded that the rate of violation at signalized intersection in Saudi Arabia is significantly higher by 15-16 times compared to the violation rate at the U.S. signalized intersections. This is a clear indication that in Saudi Arabia, there is very high rate of non-compliance at signalized intersections.

8. Conclusions and Recommendations

Several conclusions can be obtained from the results of the analysis. First, on average, in the Eastern Province, on average, there are 23.65 drivers that cross the intersection at yellow, 10.58 cross on red, 23.63 start on red, 24.32 turn right on red without stopping, and 34.6 turn right on red without stopping, for every hour. These values indicate high rate of frequencies and the dire need to improve compliance. Specific
highlight should be shed on the result that 1.31 drivers cross the street after the red light has been on for 5 seconds in an hourly basis. This is the top dangerous violation and yet some drivers are quite daring to do it. The highest rate of violation is right turn on red and as for the through vehicle violations, in order of high to low are as follows; SOR (starting on red), HNSY (not stopping in yellow), and HNSR (not stopping in red). The results also revealed that time of day, area, location, land use and street type had no significant effect on the violations. However, existence of median (MD_EXIST) minimized right turn on red violation for unclear reasons that may be attributed to the caution taken by drivers when there is a median. Additionally, the existence of left turn lane was found to positively affect the entire violations, with the exception of HSOR, indicating that the left turn lane reduces traffic violations. As for the existence of the right turn lane, the results showed it to decrease right turn on red with stopping (HRORWS), but to increase right turn on red without stopping (HRORWOS), questioning its overall benefit. Moving on to the existence of lane marking (LN_MARK), it is beneficial in that it reduces right turn on red without stop (HRORWS). Both HNSR and HRORWOS appeared to be decreased with the increase in the number of lanes, while the increase of through lanes appeared to increase the starting on red (HSOR) violation. However, the existence of pedestrian crossing decreases HSOR. This is assumed to be a reasonable outcome as drivers often steer clear of starting a conflict with pedestrians. Added to this, sight distance has to be improved because of its benefits in decreasing HRORWS and ROR violations. The results indicated that the red light violation in the Eastern Province is 7-10 times higher compared to the U.S. case. In fact, the Eastern Province obtained the highest rate of not stopping on red violation in comparison to the other two cases (Riyadh and U.S.).

Table 3. Results of one-way ANCOVA’s with covariates\textsuperscript{a}.

<table>
<thead>
<tr>
<th>Variable</th>
<th>HNSY</th>
<th>HNSR</th>
<th>HNSR5SEC</th>
<th>HSOR</th>
<th>HRORWS</th>
<th>HRORWOS</th>
<th>ROR</th>
<th>TOTVIOL</th>
</tr>
</thead>
<tbody>
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<td>TIME</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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</tr>
<tr>
<td>MD_EXIST</td>
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<td>6.18</td>
<td>–</td>
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<td>LN_MARK</td>
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</tr>
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\textsuperscript{a} Covariates used for various violations are:
- HNSY: MD_WIDTH, HVOLTHTRU, CTIME
- HNSR: MD_WIDTH, HVOLTHTRU, GTIME
- HNSR5SEC: MD_WIDTH, HVOLTHTRU,
- HSOR: HVOLT_TOT
- HRORWS: HVOL_RGT
- HRORWOS: MD_WIDTH, HFREECH, HVOL_RGT
- ROR: HVOL_RGT
- TOTVIOL: HVOLT_TOT, MD_WIDTH, GTIME
Table 4. Adjusted means for the variables that have a significant effect on violations.

<table>
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Table 5. Comparisons of violation frequencies.

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<th>US**</th>
<th>Violation type</th>
<th>Riyadh*</th>
<th>Buraidah*</th>
<th>US**</th>
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* Koushki & Ghadeer (1993) [12].
Fig. 3. Comparison of violation frequencies for not stopping on red.

Fig. 4. Comparison of violation frequencies for right turn on red.
On the basis of the above conclusions obtained from the analysis results, several recommendations can be provided to reduce violations that cause accidents in signalized intersections. The considerable number of road accidents in the Saudi context evidences the seriousness of driver non-compliance with traffic rules and regulations. The compliance to traffic signals at intersections can be improved by installing more red light running camera system used by SAHER\textsuperscript{[24]}, which will enhance compliance level of drivers with traffic signals at intersections. Improvements may also be conducted through greater enforcement levels at low traffic volume intersections, severe violation penalties, and promoting education of what exactly constitutes a traffic signal violation among the public. Based on the result that the existence of left turn lane minimizes all violations, with the exception of starting on red (HSOR), the construction of left turn lane on every approach has to be kept into consideration. Similarly, the existence of pedestrian crossing was found to minimize starting on red violation (HSOR) and hence, pedestrian crossing may be provided on every approach.

### References


سلوك عدم التقيد بإشارة التقاطعات المرورية في المنطقة الشرقية بالمملكة العربية السعودية

حسن مساعد الأحمدي
قسم الهندسة المدنية، جامعة الملك فهد للبترول والمعادن، الظهران، المملكة العربية السعودية
ahmadi@kfupm.edu.sa

المستخلص. يعتبر السائقون في المملكة العربية السعودية الذين لا يتقيدون بالإشارة الحمراء السبب الرئيس لحوادث المرور كل عام، إذ يشكلون 21٪ من إجمالي عدد الحوادث المرورية في المناطق الحضرية. تهدف هذه الدراسة في المقام الأول إلى تحديد أنواع و مدى تكرار المخالفات المرورية عند التقاطعات ذات الإشارات المرورية في المنطقة الشرقية من المملكة العربية السعودية. ولتحقيق هذا الهدف، فقد تم اختيار اثني عشر تقاطعًا لدراسة أنواع المخالفات المرورية وعلاقاتها بالحجم المروري واستخدامات الأراضي والخصائص الهندسية للتقاطعات. بناءً على تحليل البيانات التي تم الحصول عليها خلال ساعة واحدة، فقد كان عدد السائقين الذين عبروا التقاطع خلال الإشارة صفراء 23.65، أما أولئك الذين عبروا والإشارة حمراء فبلغ عدهم 10.58، وعدد السائقين الذين يبدأون القيادة والإشارة حمراء 23.63، وأخيرًا، بلغ عدد السائقين الذين استداروا للليمين عند التقاطع والإشارة حمراء دون توقف 34.6، وعدد السائقين الذين توقفوا عند الالتفاف لليمين بلغ 24.32 خلال ساعة. وبالإضافة إلى ذلك، فإن عدد السائقين الذين عبروا التقاطع حتى بعد تحول الإشارة إلى الحمراء لمدة 5 ثوان كان 13.1 في الساعة. وتوصي هذه الدراسة بالتوسع في استخدام نظام الضبط الآلي للمخالفات المرورية، والذي يعد أحد الإجراءات الفعالة للحد من قطع الإشارة الحمراء في التقاطعات، وذلك لتعزيز مستوى الامتثال للسائقين لإشارات المرور عند التقاطعات.

كلمات مفتاحية: قطع الإشارة الحمراء، التنفيذ، القيادة المحفوفة بالمخاطر، سلوك السائق.