EFFECT OF SIGNAL HEAD LOCATION ON STOP-LINE ENCROACHMENT

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الخلاصـة :

تهتم إدارة المرور في المملكة العربية السعودية لما يحدث من تجاوز السائقين لخط التوقف لدى انتظارهم عند الضـوء الأحمر على التقاطعات مما حدا بالمسؤولين لاتخاذ قرار بإزالة الإشارة البعيدة والإكتفاء بالقريبة فقط حتى يُجبر السائقون للتوقف قبل الخط لعدم تمكّنهم من رؤية الإشارة إذا تجاوزوا خط التوقف القريب.

إنَّ الهدف من هذه الدراسة هو اختبار مدى فعالية هذا الأسلوب وذلك بمقارنة التجاوزات لخط التوقف عند تقاطعات بها إشارة قريبة فقط وتقاطعات بها إشارتان قريبة وبعيدة وذلك في مدينة الدمام على الساحل الشرقي من المملكة العربية السعودية.

وقد بيَّنت هذه الدراسة وبدلالة إحصائية أنَّ التجاوزات لخط التوقف في التقاطعات التي بها إشارة قريبة فقط أكثر من التقاطعات التي بها إشارتان قريبة وبعيدة مما يشير إلى أن هذا الإجراء لم يساعد بحل المشكلة بل زادها تعقيداً.

يبدو أنَّ وجود الإشارة الضوئية البعيدة ربما يعزز احترام عدم التجاوز لخط التوقف ويُوصى هنا بعمل دراسة أعمق لهذه الظاهرة.

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ABSTRACT

A common concern among traffic police officials in Saudi Arabia is the fact that drivers encroach on the area beyond the stop-line while waiting on red at signalized approaches. In a measure to prevent this from occurring, officials have removed the far-side signal head, leaving only the one on the near-side, arguing that drivers will be able to see the signal only if they stop upstream of the near-side signal head while waiting on red.

This study tested this argument by comparing stop-line encroachments at approaches with near-side only signal heads with those having near and far-side configurations in Dammam, a city on Saudi Arabia's east coast. This study concluded that encroachments are significantly higher in the first case than in the second, suggesting that, for the study approaches, this measure has exacerbated, rather than helped, the situation in the study sample. It seems that the existence of the far-side signal head enforces the law in that it deters drivers from encroaching the area beyond the stop-line. Further study of this phenomena is recommended.

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INTRODUCTION

There is a common concern among the traffic police officials in Saudi Arabia that driver non-compliance with traffic regulations contributes significantly to the problem of roadway accidents. For example, the statistics of 1411 H (1991) cited six violations as the most common causes of accidents, as shown in Figure 1 [1]. Violations at signals form the second highest category in this breakdown. A study [2] of driver non-compliance with traffic regulations at signalized intersections in the capital and in a medium-sized urban area in Saudi Arabia found that this problem is far greater than that observed in urban areas of the United States. This study recommends that increased enforcement, an improved level of safety awareness, and a modification of geometric deficiencies are essential to improve compliance with traffic rules and regulations.

One problem faced by the enforcement agencies in Saudi Arabia is driver non-compliance at the stop-line, *i.e.*, not stopping at the stop-line of signalized intersections on red. It is common to observe drivers stopping well past the stop-line, thus encroaching on pedestrian cross-walks. This fact has been noted by the traffic police department who, consequently, took action hoping to prevent or at least minimize the problem. Approaches of signalized intersections in Saudi Arabia are normally equipped with signal heads at the near and far-sides. In an attempt to remedy the previously described behavior, the traffic police department decided to remove the far-side signal head at some signalized intersections in Dammam, a city on the east coast of Saudi Arabia, leaving only a near-side signal indication at the intersection approach. The police argued that, as a result of this arrangement, drivers would not be able to see the near-side signal indication unless they stopped at or before the stop-line at the approach.

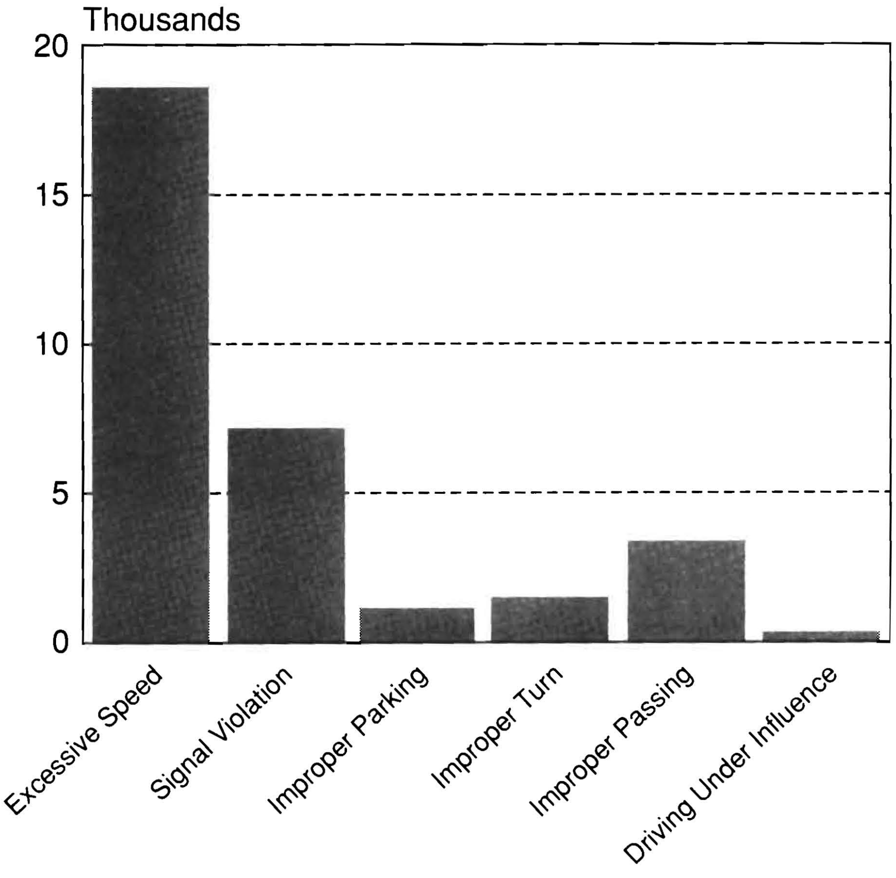

Figure 1. Violations as Accident Causative Factors in 1991 [1].

The objective of this paper is to evaluate the effectiveness of this argument by comparing driver behavior at two types of approaches, those with near and far-side signal heads and those with near-side heads.

BACKGROUND

The Manual on Uniform Traffic Control Devices (MUTCD) of the United States [3] specifies that the primary consideration in signal face placement shall be visibility. A minimum of two signal faces for through traffic shall be visible and be located on the far-side of the approach. The placement of at least one of the faces is specified to be between 40 ft (12 m) and 120 ft (36 m) and within a cone of vision of 40° (20° on either side of the approach centerline). The exact location of the faces is decided according to the geometry of the intersection. A near-side face is recommended to be as close as possible to the stop-line when the nearest (far-side) signal face is located more than 120 ft (36 m) beyond the stop-line. The purpose is, of course, to improve visibility.

Australian specifications [4] require that a minimum of three signal displays for any approach should be installed. Two of these displays should be on the far-side and one at the near-side on the left (equivalent to the right in Saudi Arabian practice where driving is on the right). More than three is only warranted when the physical conditions of the approach, such as its width or impaired visibility, make this necessary.

Saudi Arabian standards [5] specify that at least one signal indication must be provided for each approach at the near-side. Its purpose, as specified, is to indicate, in association with the stop-line, the location where vehicles should stop. Its location is one meter beyond the stop-line on the right side of the approach. When another face is provided, it should be on the median and in the near-side of the approach. An additional far-side head signal is specified on the median for approaches wider than three lanes, or alternatively, an additional near-side is placed "after" the previously specified near-side face. This decision depends on the width of the cross-street, the distance of the set-back of the stop-line from the junction, and overall visibility. Exact conditions and details are not spelled out by the standards.

Clearly, there is no definite emphasis on visibility in the Saudi Arabian standards when compared with U.S. or Australian standards. Indeed, as mentioned earlier, the emphasis in Saudi Arabian practice is only on the near-side installation with the main purpose being an indication of where drivers should stop.

DATA COLLECTION

As stated earlier, the traffic police department removed the far-side signal head from some of the intersection approaches at Dammam, the study area of this investigation, which is a commercial center on the east coast of Saudi Arabia.

The objective of this study is to conduct a comparison of encroachments of stop-lines at two categories of approaches, namely those having near and far-side signal heads (NF category) with those having a near-side signal head only (NO category). An encroachment of a stop-line is defined here as a driver's act of stopping past the stop-line while waiting on the red signal indication.

To fulfill this objective, a major divided two-way arterial having four intersections with major divided two-way arterials was chosen as the study location. These four intersections, with a total of sixteen approaches, fall into two categories. Eight of the approaches have near and far-side signal heads, and the other eight have a near-side signal head only. In the case of the latter category, the far-side signal heads were removed by the traffic police department as a remedial measure. Administrative difficulty dictated this parallel scheme of the experimental design over other possible schemes such as before–after experiments.

The study was designed so that the effect of the physical and traffic conditions other than the effect of the signal head locations on stop-line violations could be discounted. Specifically the following features were noted:

1. Because the arterial is of a short length, 2.5 kilometers, a uniform driving population for both categories can be assumed.
2. Signals at each intersection operate with one phase per entire approach *i.e.*, directional phasing, and the intersections operate in an isolated manner, *i.e.*, they are not coordinated.

3. All approaches have markings for stop-lines and pedestrian cross-walks. A signal post is located one meter downstream of the stop-line.
4. All approaches in the study intersections are three lanes wide except one intersection in each category where there is an additional exclusive left-turn lane on the major corridor on both ways. The left movement is shared with the through on all other approaches.
5. The right lane at every approach serves the right movement exclusively.
6. Overall vehicular and pedestrian activities are similar among all the approaches.
7. Approaches with a near-side installation only have a single signal head on the median, and those with a near and far-side configuration have two heads on the median, before and after the intersection.
8. All signal heads are pole-mounted at a height of 2.50 m.
9. Intersections are level and clear from obstructions so there is no restriction on sight distance.

The above conditions restricted the number of suitable approaches for the study. Sixteen approaches were selected: eight in each category. Although this sample size may seem to be small, it should be realized that the reliability of the encroachment measurements is actually a function of the duration of the study and not the number of approaches. The duration of the study at these approaches to obtain measurements with acceptable levels of error was calculated as described below. Furthermore, Dammam is a relatively small urban area (about 400 000 in population) that has few signalized intersections (about 35) and the traffic police department removed the far-side signal head only from a few intersections, which restricted the number of approaches suitable for this study.

The following formula was used in the determination of the study duration which is suggested in traffic conflict procedures [6]:

$$n = \left[\frac{100Z}{p} \frac{\sigma_e}{\bar{Y}} \right]^2$$

where

n = number of hours required to estimate the hourly traffic conflict ($\bar{Y}$),

Z = Statistics from the normal distribution defined by a significant α (on confidence level of $1-\alpha$),

p = $\pm$ percent error in estimating $\bar{Y}$, and

σ_e = the hourly standard deviation.

Encroachment counts at each approach type were observed for two hours, a total of sixteen hours for each category. Verification on the sufficiency of the observation period was carried out using the formula above with suggested values (see Glauz & Migletz [6]) for $Z = 1.28$ (at $\alpha = 20\%$), $p = \pm 40$ percent, and estimates from the sample for the standard deviation and the mean of 3.2 and 3.4 respectively for the NF type and 1.3 and 6.8 respectively for the NO type. The parameter p of ± 40 percent was selected in conformity with the practice in traffic conflict experiments, which can be as high as ± 50 percent (for instance, see example on p. 11, in Glauz and Migletz [6]). The formula gives nine hours for the NF type and one hour for the NO type. The periods of observation actually made were 16 hours for each type of approach, which are higher than the calculated ones.

Encroachment counts were conducted on a typical weekday, Monday (equivalent to U.S. Wednesday), during the afternoon rush-hour, as mentioned, for 16 hours for each category of approaches. Of course, only the front vehicles waiting on red were considered. Other drivers' acts, such as crossing on red, were not considered. Stop-line encroachments on the right lane were not considered because a right turn on red is common practice in Saudi Arabia. Geometric and traffic information such as cycle length, split, and number of lanes, was also collected. Observers were trained for their tasks and were inconspicuous during the data collection periods.

ANALYSIS AND RESULTS

Two tests were performed for testing the differences in encroachments between NO and NF approaches. In the first test, which pools all the counts for NO and NF categories separately, the proportions of drivers in the front of the queues encroaching the stop line were found for all approaches in the NO and NF categories separately and these two proportions were compared using appropriate test statistics. In the second test, first, encroachment rates per lane per cycle per approach were calculated for the eight approaches in each category and they were compared. Then, the mean encroachment rates in the NO and NF categories were compared using t-statistics. These tests are described in the following paragraphs.

Testing for Equality of Proportions of Encroachments

The total number of drivers encroaching and not encroaching in the front of the queue and their proportions are given in Table 1. It should be noted that the proportion of encroachment in the NO category (0.37) is much higher than the NF category (0.17). For the proportions, the null hypothesis to be tested is:

$$H_0 : p_{\mathrm{NO}} = p_{\mathrm{NF}}$$

where p_{NO} and p_{NF} are the proportions of encroachments at the two categories. The alternative hypothesis is

$$H_1 : p_{\mathrm{NO}} > p_{\mathrm{NF}} .$$

For this purpose, the following test statistic is used [7]:

$$Z = \frac{\hat{p}_{\mathrm{NO}} - \hat{p}_{\mathrm{NF}}}{\sqrt{\hat{p}\hat{q}\left[\frac{1}{m_{\mathrm{NF}}} + \frac{1}{m_{\mathrm{NO}}}\right]}} ,$$

where

Z = the standard normal value,

$\hat{p}$ = the pooled estimate of the proportion, *i.e.*, the ratio of the total encroachment counts to the total observed counts,

$\hat{q}$ = $1 - \hat{p}$

$m_{\mathrm{NF}}, m_{\mathrm{NO}}$ = total counts of encroachments and no encroachments in each category.

Table 1. Observed Counts and (Proportion)* of Encroachments and No Encroachments at the Approaches.

	Approach Type	
	NO	NF
Encroachment	108	55
	(0.37)	(0.17)
No Encroachment	186	262
	(0.63)	(0.83)

*Proportion is computed from the columns total.

This value is found to be 5.57 while the critical normal standard value (Z_{cr}) for confidence level of 97.5 percent is 1.96. These two values (5.57 *versus* 1.96) suggest that the null hypothesis is rejected, implying that the proportion of encroachments in the NO category is significantly higher than those in the NF category.

Comparison of the Encroachment Rates and Testing the Differences Between Their Means

It is of interest to investigate the encroachments of the stop-line as a rate rather than as a count in order to normalize the variations in the number of lanes and the number of cycles within the observation period per approach. For this, the encroachment rates for all approaches are computed as follows:

$$ER = \frac{EC}{L * N_c}$$

where

ER = encroachment rate per lane per cycle per approach;

EC = encroachment counts during two hours at the approach excluding those on the right lane;

L = number of lanes at the approach excluding the right lane; and

N_c = number of signal cycles occurring during the two-hour observation period of the approach,

$$= \frac{\text{7200 seconds per 2 hours}}{\text{cycle length (seconds)}} .$$

As can be seen, ER was computed on an approach basis and it is expressed as per lane, per cycle, to normalize the exposure effect resulting from both the number of lanes and the cycle length. This is because, first, the study approaches are either three- or four-lanes wide, *i.e.*, the greater the number of lanes, the more the encroachment counts. Second, because cycle length at the study intersections varies from 100 to 120 seconds, EC is expected to increase when the cycle length decreases because the occurrence of the red interval, during which encroachments to the stop-line result, increases. At this point, it should be realized that each study intersection has four approaches and the cycle split among the approaches of each study intersection is 25 percent.

Figure 2 shows a graphical representation of the encroachment rates for the study approaches. The rates for the NF approaches are all lower than the rates for the NO ones except that one observation is high in the NF type and one observation is low in the NO type. This shows that the encroachment rates are, in general, higher for the NO type than the NF type. While the traffic police department took the measure of removing the far-side signal head in order to discourage encroachments of the stop-line, the distribution of counts and the encroachment rates for the NO case suggest that the opposite is happening.

The mean encroachment rates are 0.3756 and 0.1654 for the NO and NF type, respectively. The mean for the NO case is higher than that for the NF case by 128 percent. Testing the equality of these means is carried out using the null hypothesis

$$H_O: \overline{X}_{NO} = \overline{X}_{NF}$$

where $\overline{X}_{NO}$ and $\overline{X}_{NF}$ represent the mean encroachment rate per lane per cycle for the respective configuration.

The above hypothesis is tested using the t-test with the following t statistics which is based on the quality of variances of the two categories (NO and NF cases):

$$t = \frac{\overline{X}_{NO} - \overline{X}_{NF}}{Sp\sqrt{\frac{1}{n_{NO}} + \frac{1}{n_{NF}}}} ,$$

where

$\overline{X}_{NO}$, $\overline{X}_{NF}$ are defined earlier,

$$Sp^2 = \frac{(n_{NO}-1)S_{NO}^2 + (n_{NF}-1)S_{NF}^2}{n_{NO}+n_{NF}-2}$$

S_{NO} = standard deviation for near-only signal installation,

S_{NF} = standard deviation for near and far signal installations, and

n_{NO} and n_{NF} = sample size for each installation.

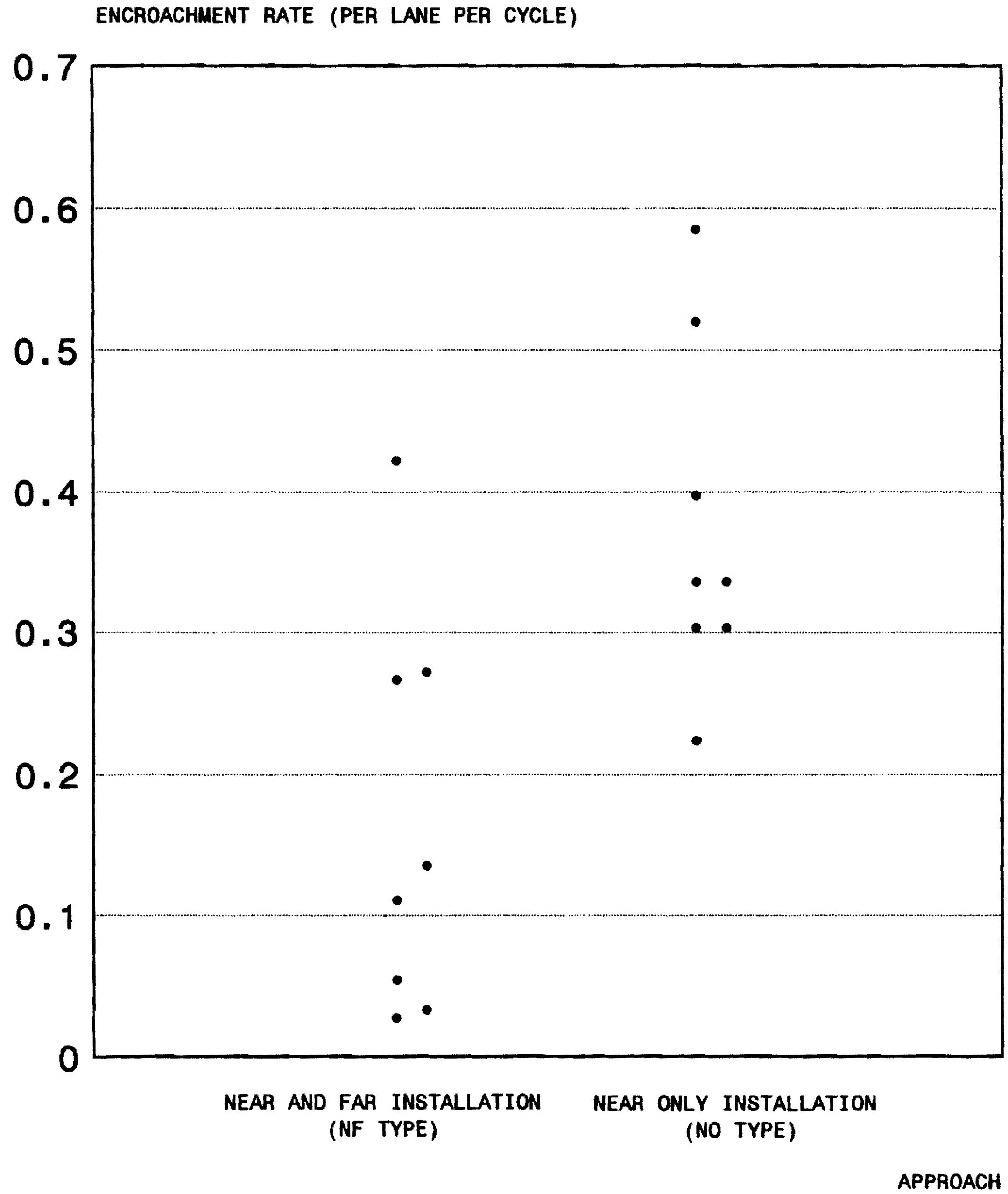

Figure 2. Encroachment Rates at the Study Approaches.

So the null hypothesis is rejected at a significance level (α) whenever

$$t < -t_{\frac{\alpha}{2},\nu} \quad \text{or} \quad t > t_{\frac{\alpha}{2},\nu}$$

where ν is the degree of freedom ($n_{NO} + n_{NF} - 2$) and $t_{\alpha/2,\nu}$ and $-t_{\alpha/2,\nu}$ are obtained from tables of the t-distribution. Table 2 shows a summary of the t-test. The two-tailed t-test indicates that there is a significant difference between the mean encroachment rates of NO and NF configurations at the 5 percent level, or, equivalently, the null hypothesis of equal means can be rejected with 95 percent confidence.

The results of the above analyses indicate that encroachment of the stop-line is more for the NO case than the NF case. In other words, the existence of the far side signal face seem to deter the potential offenders.

Table 2. Summary of the *t*-Test.

Configuration Type	Sample Size (Approaches)	Mean Encroachment Rate, Encroachment/lane/cycle (Standard Deviation)
NO	8	0.376 (0.121)
NF	8	0.165 (0.141)
t-statistics = 3.198		
$t_{0.05/2,14}$ = 2.140		

Note: NO: only near-side installation; NF: near- and far-side installation.

CONCLUSIONS AND RECOMMENDATION

The results of this study, based on the limited sample of approaches in Dammam, indicate that the strategy of removing the far-signal head does not seem to lower the frequency of encroachments of the stop-line but, contrary to the expectations of the police department, it seems to increase them. It seems that the existence of the far-side signal head enforces the law and acts as a deterrent to encroachments of the stop-line. Further studies, and perhaps with different experimental designs such as the before–after type, should be carried out for other types of signalized intersections and at other locations to uncover further the effect of this strategy, particularly from behavioral point of view. However, these findings indicate the need for a more cautious approach before applying such drastic changes as the removal of far-side signal faces.

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