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EFFECTIVENESS OF NEWLY INTRODUCED VARIABLE MESSAGE SIGNS IN AL-KHOBAR, SAUDI ARABIA

ABSTRACT

Recently, Variable Message Signs (VMS) were introduced in Saudi Arabia and their reliability under local environment is being tested. This paper aims to evaluate the possible response of the drivers to VMS when used for messages related to traffic conditions. A major arterial in Al-Khobar city in Saudi Arabia with a massive VMS board was selected for this paper. The evaluation process started by interviewing drivers selected randomly from the study area. About 77% of the interviewed drivers indicated positive attitude toward messages requesting change of route. The drivers' interviews demonstrated statistical relationship between the degree of response to messages requesting change of route and the reason for such request. The maximum response was for messages related to accidents, roadwork activities, and traffic congestion. A field experiment was also conducted along the studied arterial. It was found that VMS statistically increased the percentage of diverted traffic during specific peak periods.

KEY WORDS

VMS; ITS; traffic congestion; traffic information; message signs

1. INTRODUCTION

Traffic congestion is a major national problem in Saudi Arabia. The local traffic characteristics are different from most of the other countries. The major cities in the Kingdom possess good modern road networks with huge daily traffic similar to any major city in the USA and Europe. However, unlike most industrialized countries, Saudi Arabia has a poor and limited urban mass transportation system. With the exception of a poor bus service, there is no other urban mass transportation system in the country. Passenger car, practically speaking, is the only mode of transportation in all the cities. This situation exerted a tremendous pressure on the urban road network in all major cities where congestion reached intolerable levels. Another unique feature of the local traffic is the fact that most drivers are not native and come from a wide spectrum of ethnic and socioeconomic backgrounds. Currently, there are 3.9 million active driving licenses in Saudi Arabia, out of which 56% are for expatriate drivers [1]. Such heterogeneous driver population with different driving habits and linguistic communication problems adds to the severity of the congestion problem. Local traffic authorities are currently addressing the congestion problem by planning a massive mass transport system of underground networks. The local authorities are also trying to adopt the Intelligent Transportation System (ITS) as a possible immediate means for mitigating the congestion problem. Variable Message Signs (VMS) is an ITS technique recently introduced in the country to inform the drivers about the instantaneous traffic conditions and to advise them how to cope with it. Usually, such effort enhances traffic operation and improves safety.

Currently, these VMS display only general static information for testing their reliability under local conditions and to familiarize drivers with this technology. The main objective of this paper is to evaluate the response of the drivers to VMS when used for conveying messages related to instantaneous traffic conditions.

2. BACKGROUND

VMS is one of the popular technologies available for disseminating traffic-related information from the roadside. The European Committee for Standardization defines VMS as "a sign for the purpose of displaying one of a number of messages that may be changed or switched on or off as required" [2]. VMS is typically used to disseminate early warning messages, advisory messages, and alternative route messages [3]. Many researchers reported possible benefits of VMS in terms of safety improvements. Dos Santos [4] reported possible reduction of rear-end collisions as result of using a combination of VMS and variable speed limits.

Borrough [5] and Lee et al. [6] also reported possible decrease in the number of crashes as a result of applying VMS. Other researchers reported positive effect of VMS on reducing travel time, alleviating congestion and improving system performance [7, 8, 9].

Several studies were conducted in different countries to measure the impact of variable message signs by conducting field observation of the drivers' response to VMS and also through questionnaires to measure the drivers' intended response to VMS suggestions and information. A recent survey conducted in Missouri to evaluate the drivers' response to VMS along rural freeway revealed that 94% of the surveyed drivers claimed that they will abide with the instructions and suggestions of VMS [10]. Another study conducted in Amsterdam showed that more than 70% of the drivers were sometimes influenced by VMS information [11]. A driver questionnaire conducted to evaluate the impact of VMS on a freeway in Wisconsin showed that approximately 70% of the respondents would alter their route based on traffic information displayed on VMS [12]. A telephone survey in the Los Angeles area indicated that about 70% of the interviewed commuters would divert to alternative route if adequate traffic information were provided to them [13]. A study in London used field observation and questionnaire to investigate the effect of different VMS messages on the route choice of the drivers. The number of drivers who diverted as observed in the field was only one-fifth of the number of drivers who would divert as predicted from the questionnaire [14]. A field study conducted in Oslo to evaluate the effect of VMS on route choice concluded that there was a high compliance with VMS suggestions, in which approximately 20% of the vehicles changed route choice according to VMS suggestions [15]. The effect of VMS on drivers to alter their route choice varied considerably in other studies. Cummings [16] reported the effect to be as low as 4% whereas Davidsson and Taylor [17] reported an astounding value of 41%.

A recent study conducted in Oslo showed that incident information is the most useful kind of information that can be disseminated via VMS and that congestion warning messages have no effect on route selection unless they are associated with traffic incidents [18]. Nygardhs and Helmers [19] conducted a comprehensive literature review on VMS studies about European conditions and studies published in Europe between the years 2000 and 2005. In one of these reviewed studies, it was concluded that variable speed limit signs were very frequently followed. Another study reviewed by Nygardhs and Helmers [19] hinted to some

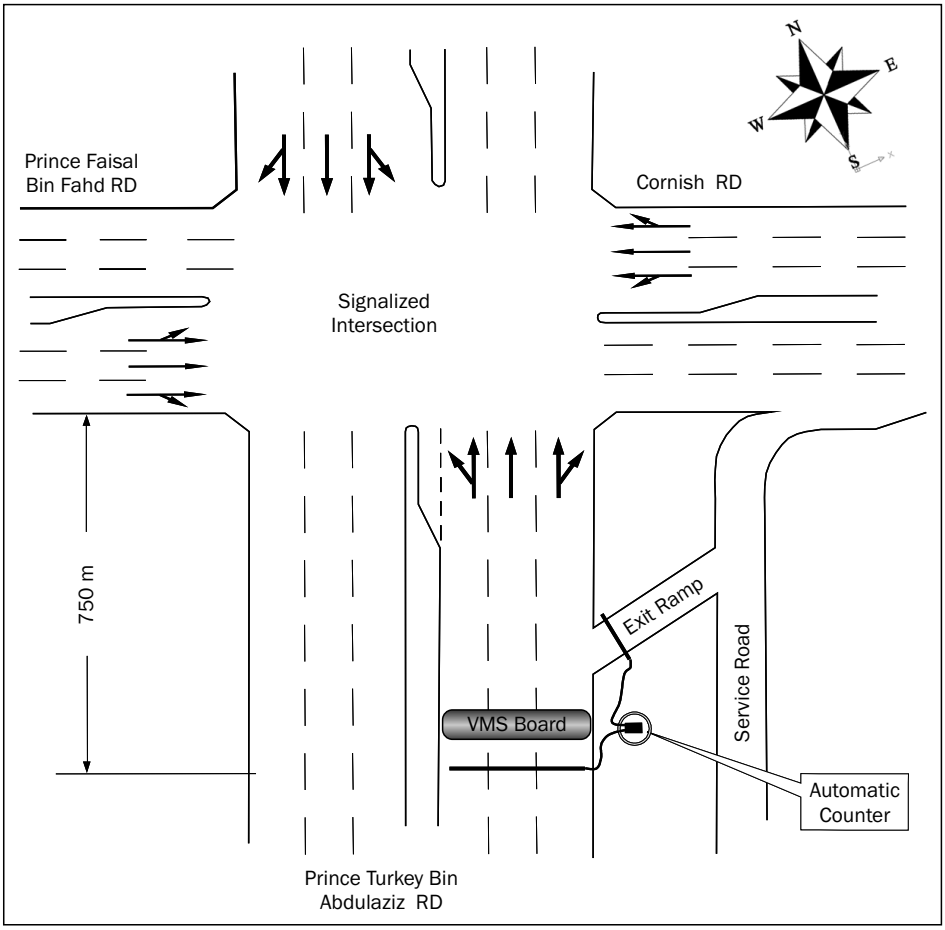

Figure 1 - Study site

differences between the drivers in Canada and the United Kingdom in terms of their attitude toward VMS. Another survey study in Wisconsin indicated that drivers consider VMS useful in reporting weather status and traffic conditions [12]. Peeta and Ramos [20] investigated the drivers' response to traffic information disseminated through VMS and found a strong correlation between VMS message type and the drivers' response.

3. TEST SITE

The field study in this paper was conducted in 2012 along Prince Turkey Bin Abdulaziz Road which is a major arterial in Al-Khobar city with a massive VMS board. This arterial was the only one in the city with VMS equipment at the time of this research. The area in the vicinity of the selected arterial is considered to be one of the elite recreational and commercial districts of the city. The VMS board is located 750 meters before a very busy signalized intersection. The arterial has a parallel service road with an exit slip ramp 70 metres before the VMS board, as shown in *Figure 1*. The service road provides access to several commercial and recreational activities spread all over the east side of the arterial.

4. METHODOLOGY

This paper studied the response of the drivers to VMS when used to convey dynamic traffic information and instructions through two tracks. In the first track, random samples of drivers were interviewed to explore their intended responses to such information when disseminated via VMS. Subsequently, the second track assessed the response of the drivers in the field to such messages.

Daily peak traffic along the studied arterial (Prince Turkey Bin Abdulaziz Road) usually starts after 8 PM and can extend up to midnight. This time interval coincides with the dinner and shopping periods in the study area. During peak period, there is usually a heavy right-turning volume from Prince Turkey Bin Abdulaziz Road onto the Cornish Road at the signalized intersection shown in *Figure 1*. Although the local regulations allow right turn during red phase, most of the time vehicles turning right at this intersection have to wait for more than one cycle to clear the intersection during the peak period. Turning right to the Cornish Road can also be done far before the signalized intersection by exiting the arterial from the exit slip ramp near the VMS board and then use the parallel service road to join the Cornish Road as shown in *Figure 1*.

In the first track of this research, an interview was conducted with random samples of drivers who used the selected arterial to assess their anticipated response to VMS. The interviews were conducted both in Arabic (national language) and in English for non-Arabic speaking drivers. The first part of the interview was related to personal characteristics of the drivers, such as age, level of education and driving experience. In the second part, the drivers were asked to assess the anticipated benefits of VMS on a subjective scale ranging between highly helpful and not helpful. The last part of the interview explored the responses of the drivers to VMS requesting them to change their route due to some traffic circumstances. In this part of the interview, the responses were measured on a subjective scale of four categories, namely never complied with VMS request, rarely complied with VMS request, usually complied with VMS request, and always complied with VMS request. The sample size of the interviewed drivers was originally based on estimating the percentage of drivers who will respond positively to VMS at a specific confidence level. The following equation was used to estimate the number of interviewed drivers [21]:

$$N = p * q * (z_{\alpha/2}/d)^2 \quad (1)$$

where:

- p – Proportion of drivers who responded positively to VMS;
- q – Proportion of drivers who responded negatively to VMS ($q = 1 - p$);
- d – Permitted error;
- $z_{\alpha/2}$ – "Z" value of normal distribution.

To have the maximum sample size, "p" and "q" were assumed to be 0.5 [21]. The permitted error was taken to be ±0.1 at 90% confidence level. As such, the estimated sample size was 68 drivers. Sudman [22] suggested that the sample should be large enough to encompass a minimum of 100 elements in each category of the population which is thought to be important for the study. Accordingly, and since the drivers who were interviewed can be thought of as coming from two major groups (experienced VMS or, did not experience VMS while driving), the sample size was generously increased to 250 drivers. This size will reduce the permitted error "d" in Equation (1) from ±0.1 to only ±0.052 at 90% confidence level.

In the second track of this research, the percentage of the northbound traffic diverted from Prince Turkey Bin Abdulaziz Road to the right through the slip exit ramp was monitored for three days. After that, the VMS was activated to advise the drivers who want to make a right turn at the signalized intersection to use the exit slip ramp during the peak periods when the signalized intersection is very busy. This was conveyed to the drivers in Arabic and English messages. The percentage of diverted traffic to the service road at the slip exit ramp was again monitored for three days. The percentage of drivers using the slip exit ramp before activating the VMS was compared

to the percentage of drivers using the same ramp when the VMS was operational. The comparison was done over the same days of the week and hours of the day.

5. DRIVERS' INTERVIEWS

The interview sample consisted of 20% non-Arabic speaking, 49% Saudi and the remaining (31%) were Arabic speaking non-Saudi drivers. About 30% of the drivers had less than 3 years driving experience and another 30% of them had more than 6 years of experience. About 53% of the drivers had college level education. The age of 18% of the drivers was below 20 years of age and 26% of them were older than 30. About 85% of the drivers acknowledged that it is important to inform the drivers about the instantaneous traffic conditions through radio stations or VMS technology. About 15% of the interviewed drivers never heard about VMS, and 21% of them were familiar with this technology but never experienced it while driving. Occasionally, 41% of the interviewed drivers were exposed to VMS in other countries (two to three times in their driving history), while 23% of the drivers were exposed to it regularly in other countries.

About 80% of the interviewed drivers had positive attitude toward VMS. These drivers indicated that VMS would improve traffic operation, reduce driving stress and ultimately improve safety. Only 6% of the drivers indicated that they did not trust the information disseminated by VMS and 10% of the drivers had no opinion on this issue.

To further investigate in detail the response of the drivers to VMS, they were asked to declare their reaction to the message instructing them to change the route they were using due to a number of circumstances as shown in *Table 1*.

Table 1 - Responses to VMS requesting change of route

Reason to change the route	Response			
	Never change route (%)	Rarely change route (%)	Usually change route (%)	Always change route (%)
Accident	4	12	37	47
Traffic congestion	4	14	37	45
Roadwork activities	3	15	38	44
Adverse weather	5	24	41	30
Special event	13	22	28	37

To have a more holistic picture of the drivers' response to VMS, *Table 1* was rearranged by consolidating the first two columns (never and rarely change route) into one column as "Negative response to change of route". Similarly, the third and fourth columns (usually and always change route) were merged into one column as "Positive response to change of route". *Table 2* shows the consolidated information of *Table 1*.

Table 2 - Consolidated responses to change of route messages

Reason to change the route	Negative response to change of route (%)	Positive response to change of route (%)
Accident	16	84
Traffic congestion	18	82
Roadwork activities	18	82
Adverse weather	29	71
Special event	35	65
Average response	23	77

It is interesting to notice in *Table 2* that the percentage of positive responses to the first three "Reasons to change route" is between 82% and 84%, which is quite high. Traffic accidents, congestion, and roadwork activities are palpable reasons and understood by the drivers in the area. Consequently, high positive response to such reasons was expected. On the other hand, the positive response in adverse weather conditions and special events was relatively low. These two "Reasons to change the route" are so rare in the study area that their consequences were not appreciated by the drivers. This might explain the relatively low percentage of positive response in these two situations.

The collected data was also statistically analyzed through contingency tables and chi-square (χ^2) test which was used to compare the observation to the expectation in these tables. The χ^2 value in each cell of the contingency tables was calculated by squaring the difference between the observed and expected frequencies and dividing it by the expected frequency. The sum of χ^2 values of all cells in a contingency table gives the total χ^2 value reported at the end of the table. The null hypothesis (H_0) used in any contingency table was "no relationship" between the drivers' response to VMS and one of the factors under investigation. The confidence level used in all tables was 90% and consequently, H_0 was rejected in any table with P-value less than 0.1. To determine which cell(s) of the table statistically contributed to the rejection of H_0, the χ^2 of each cell was compared to 2.7, which is the tabulated χ^2 at 90% confidence with 1 degree of freedom. Any cell with χ^2 greater than 2.7 indicates that the cell contributed to the rejection of H_0 of the contingency table under consideration. The high chi-square value of *Table 3* indicates that the observed and expected frequencies in some of the cells are statistically different. This in turn suggests a strong relation between the response to VMS (changing the route) and the reason to change the route. All the cells in the third column of *Table 3* (Negative response to change of route) con-

tributed statistically to this conclusion (i.e. $\chi^2 > 2.7$ in each cell). The observed number of negative responses in the cases of accidents, traffic congestion, and roadwork activities were statistically well below the expected numbers according to the contingency table (*Table 3*). On the contrary, the observed number of negative responses in the cases of adverse weather conditions and special events were statistically much larger than the expected numbers. Consequently, the drivers were expected to respond more favourably to change of route messages when the causes of these messages were palpable to drivers, such as accidents, congestion or roadwork activities.

Table 3 - Effect of reason for change of route on response

Reason to change the route	Count	Negative response to change of route	Positive response to change of route
Accident	Observed	40	210
	Expected	58.0	192.0
	χ^2	5.6	1.7
Traffic congestion	Observed	45	205
	Expected	58.0	192.0
	χ^2	2.9	0.9
Roadwork activities	Observed	45	205
	Expected	58.0	192.0
	χ^2	2.9	0.9
Adverse weather	Observed	73	177
	Expected	58.0	192.0
	χ^2	3.9	1.2
Special event	Observed	87	163
	Expected	58.0	192.0
	χ^2	14.5	4.4
χ^2 = 38.793, DF = 4, P-value = 0.000			

The effect of age, language, driving experience, nationality, and educational level on the drivers' response to VMS was also statistically tested using contingency tables and χ^2 test. None of these variables had any statistical effect on the drivers' response when the messages were associated with traffic accidents or congestion. On the other hand, messages related to roadwork activities had the least effect on drivers who were below 20 years of age, as can be seen from *Table 4*. Similar statistical analysis indicated that the same age group had also the least positive response to change of route messages when the messages were related to special events. The data analysis also suggested that the drivers with less than 3 years of driving experience in the country had the highest positive response to change of route messages which are related to adverse weather conditions. Further analysis of the data showed that non-Arab drivers (expatriates) had the highest positive response to change of route messages when these messages were related to special events, while Saudi drivers (natives) had the least positive response to such messages. Native drivers had also the least positive response when the messages are related to adverse weather conditions. All of this suggested that Saudi drivers who are very familiar with the local driving environment are less responsive to messages related to rare events in the study area, such as adverse weather conditions.

Table 4 - Effect of age on response to change route messages related to roadwork activities

Age of driver (Years)	Count	Negative response to change of route	Positive response to change of route
Less than 20	Observed	15	29
	Expected	8.1	35.9
	χ^2	5.9	1.3
20-30	Observed	21	121
	Expected	26.1	115.9
	χ^2	1	0.2
More than 30	Observed	10	54
	Expected	11.7	52.2
	χ^2	0.3	0.06
χ^2 = 8.777, DF = 2, P-value = 0.012			

6. FIELD EXPERIMENT

A continuous traffic count was conducted along the studied arterial and the slip exit ramp to identify the peak periods. Typically, the highest traffic volume in the study area occurs between the last day of the weekdays and the first day of the weekend. The traffic count was done over the last two weekdays of the week and the following day of the weekend. Thursday and Friday are the weekends in Saudi Arabia; consequently, the continuous traffic count was done on Tuesday, Wednesday and Thursday. *Figure 2* shows that the peak traffic is around 10 PM on Tuesday and Wednesday while it is almost at 8 PM on Thursday.

The northbound traffic exiting the arterial to the parallel service road using the right slip ramp was simultaneously monitored with the total traffic of the arterial during these three days for two consecutive weeks. In the first week, the VMS was completely off. The highest right-turning volume on the exit ramp was approximately between 8 PM and midnight on Wednesday and Thursday as shown in *Figure 3*. No clear right turning peak existed on Tuesday. *Figure 4* indicates that the right-turning volume as a percentage of the total traffic was also at its peak during the same peak period on Wednesday and Thursday. This peak period on the exit

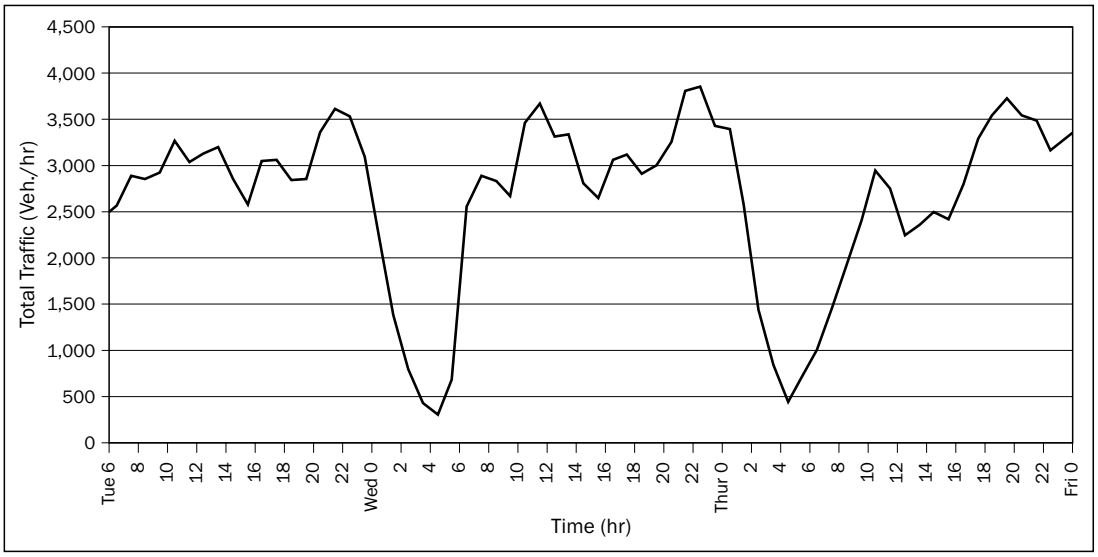

Figure 2 - Total traffic count before the slip ramp

ramp nearly coincides with the peak period of the total arterial traffic previously shown in *Figure 2*.

In the second week, the VMS was activated on Tuesday, Wednesday, and Thursday. During the peak period (8 PM-midnight), the VMS advised drivers who wanted to turn right at the downstream signalized intersection, to execute the right turn from the upstream exit slip ramp. At all other times, the VMS disseminated general safety tips and information.

Figures 3 and 4 indicate that there was a clear increase in the right-turning volume when VMS was operational on Wednesday and Thursday during the peak period between 8 PM and midnight. On Tuesday, the effect of VMS seems practically negligible. It seems that the effect of VMS is evident when the turning volume exceeds 300 vehicles per hour, which is approximately equal to 10% of the total traffic along this arterial.

The binomial distribution was used to statistically compare the proportion of turning traffic when VMS was off to the turning proportion when VMS was on during the peak period (8 PM to midnight) on Wednesday and Thursday. Tuesday was completely excluded from this comparison since VMS has practically negligible effect throughout the day as shown in Figures 3 and 4.

The total traffic was considered as "*n*" repeated Bernoulli trials of which the success probability "*p*" was the probability of turning right. This probability "*p*" was estimated by dividing the number of vehicles turning right over the total traffic in sample "*n*". Confidence interval for "*p*" was calculated using the following equation [21]:

$$p \pm z_{\alpha/2}\sqrt{p(1-p)/n} \tag{2}$$

where $z_{\alpha/2}$ is the value of the normal distribution and the remaining parameters of the equation are as de-

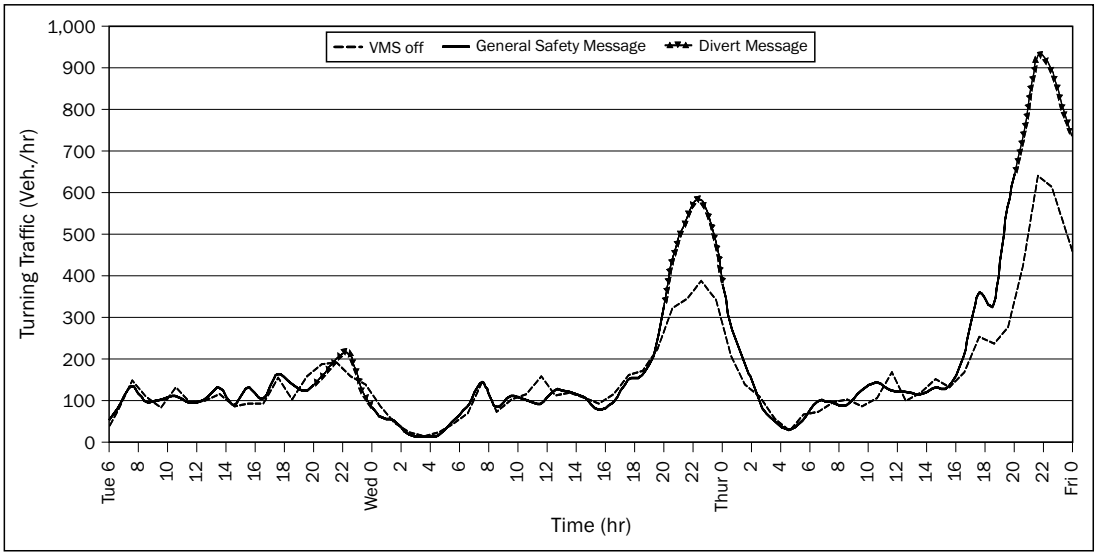

Figure 3 – Turning traffic count at the slip ramp

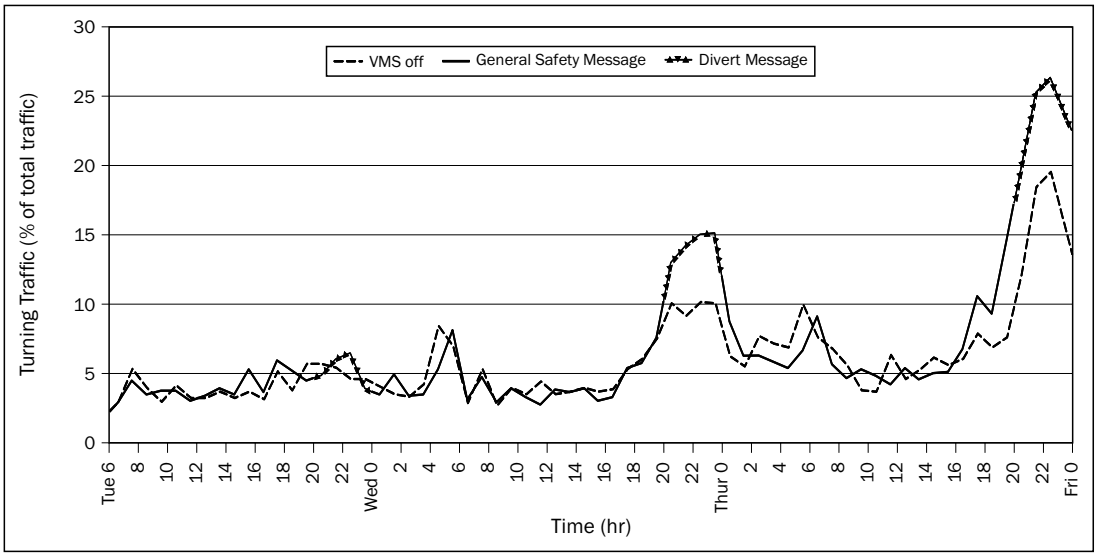

Figure 4 - Percentage of total traffic turning at the slip ramp

scribed above. *Table 5* shows the right-turning proportion "*p*" with a 90% confidence interval for each hour of the peak period on Wednesday and Thursday using Equation (2). The proportion of turning traffic "*p*" when VMS was on is always greater than "*p*" when the VMS was off in each hour of *Table 5*. The 90% confidence intervals for the proportion of turning traffic when VMS was off do not overlap with confidence intervals of the turning traffic while VMS was on. Therefore, it can be concluded that VMS statistically increased the proportion of turning traffic. This was true for Wednesday and Thursday, but not true for Tuesday. The additional turning traffic as result of VMS ranged between 3.0% at 8 PM on Wednesday and 8.2% at 11 PM on Thursday with an overall average of 5.9% for both days. Consequently, it can be concluded that VMS statistically increased the proportion of the right-turning traffic at the right exit ramp during these times. This conclusion is supported by the fact that the percentage of the total traffic turning right at the downstream intersection (see *Figure 1*) during the PM peak period of Wednesday and Thursday was reduced on the average from 3%

Table 5 - Proportion of total traffic exiting to the right using slip ramp on Wednesday and Thursday

Time	Day	VMS off	VMS on	Difference (column 3-column 2)
8-9 PM	Wednesday	0.100 (0.091-0.109)*	0.130 (0.120-0.140)*	0.030
	Thursday	0.121 (0.112-0.130)*	0.197 (0.186-0.208)*	0.076
9-10 PM	Wednesday	0.091 (0.083-0.099)*	0.141 (0.132-0.150)*	0.050
	Thursday	0.185 (0.174-0.196)*	0.252 (0.240-0.264)*	0.067
10-11 PM	Wednesday	0.101 (0.093-0.109)*	0.150 (0.141-0.159)*	0.049
	Thursday	0.195 (0.183-0.207)*	0.263 (0.251-0.275)*	0.067
11 PM-midnight	Wednesday	0.100 (0.092-0.108)*	0.150 (0.140-0.160)*	0.050
	Thursday	0.154 (0.144-0.164)*	0.236 (0.224-0.248)*	0.082
Average	Wednesday	0.098 (0.094-0.102)*	0.143 (0.138-0.148)*	0.045
	Thursday	0.163 (0.158-0.168)*	0.236 (0.230-0.242)*	0.073

**: 90% confidence interval*

when VMS was off to only 1% while VMS was active. This indicates that more drivers used the right exit ramp when VMS was on.

7. CONCLUSION

About 80% of the interviewed drivers had positive attitude toward VMS in spite of the fact that about one-third of them never experienced the VMS technology. Most of the drivers felt that VMS can improve traffic operation and safety. About 82% of the interviewed drivers indicated that they would respond positively to messages requesting change of route for reasons related to accidents, congestion, and roadwork activities. The positive response rate was lower for messages related to special events and adverse weather conditions. Overall, 77% of the interviewed drivers indicated positive attitude toward messages requesting change of route. This percentage is within the 70%-94% range reported by the studies reviewed in this paper. The drivers' interviews demonstrated a statistical relationship between the degree of response to messages requesting change of route and the reason for such request. The drivers seem to respond more favourably to change of route messages when the causes of these messages are palpable to drivers in the study area, such as accidents and traffic congestion. Adverse weather conditions and special events which are extremely rare in the study area had statistically less positive response from the interviewed drivers. Age, language, nationality, and educational level had no statistical effect on the drivers' responses when the messages were associated with traffic accidents or congestion. Saudi drivers seem to be less influenced by change of route messages which are related to rare events in the study area, such as adverse weather conditions.

The field experiment proved that change of route message which is related to congestion was statistically effective in increasing the percentage of traffic exiting the arterial at the slip exit ramp upstream from the congested signalized intersection. The additional turning traffic at the exit ramp while VMS displayed the change of route message ranged between 3.0% and 8.2% of the total traffic along the arterial depending on the day of the week and hour of the day. This percentage is on the low end of the values reported in other studies which range from 4% to 41%. The overall average of this study showed that 5.9% of the drivers abided by the VMS. This percentage (5.9%) is only 0.07 of the percentage of interviewed drivers who claimed that they would obey the VMS when implemented. Taking into consideration that VMS is a new concept in the study area, its effect is expected to increase with time and through professional publicity campaigns. All the findings of this study indicate that VMS is a promising concept in enhancing traffic operation, especially if used in circumstances which are palpable to drivers in the study area, such as accidents, congestion and roadwork activities.

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خلاصة

تقييم فعالية اللوحات الإلكترونية المتغيرة المستخدمة حديثا في مدينة الخبر في المملكة العربية السعودية

تم مؤخرا البدء باستخدام اللوحات الإلكترونية المتغيرة في المملكة العربية السعودية واختبار مصداقيتها في ظل الظروف البيئية المحيطة في بعض المواقع. وتهدف هذه الدراسة إلى تقييم استجابة السائقين لهذه اللوحات عند عرضها رسائل متعلقة بأوضاع الحركة المرورية على الطرق. وقد تم اختيار طريق شرياني في مدينة الخبر في المملكة العربية السعودية يحمل لوحة إلكترونية كبيرة لهذه الدراسة. وقد بدأت عملية التقييم بإجراء مقابلة مع عينة عشوائية من السائقين في محيط منطقة الدراسة .وقد أفاد حوالي 77٪ من السائقين الذين تمت مقابلتهم بأنهم سيتعاملون بإيجابية تجاه الرسائل التي تطلب منهم تغيير المسار. كما أظهرت نتائج المقابلات وجود علاقة إحصائية بين درجة استجابة السائقين للرسائل التي تطلب تغيير المسار وسبب مثل هذا الطلب. وقد تبين أن أقصى استجابة كانت لتلك الرسائل التي تعرض وجود حوادث، أو أعمال الطرق، أو ازدحاماً مرورياً. كما تم إجراء تجربة في الموقع على الطريق الخاضع للدراسة أثبت إحصائيا أن استخدام مثل هذه اللوحات الإلكترونية أدى إلى زيادة نسبة تحويل الحركة المرورية خلال فترات الذروة.

الكلمات الرئيسة

اللوحات الإلكترونية المتغيرة، أنظمة المرور الذكية، الازدحام المروري، رسائل الإشارات، المعلومات المرورية

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