Effectiveness of VMS Messages in Influencing the Motorists' Travel Behaviour

Banishree Ghosh[1] Yuanzheng Zhu[2] Justin Dauwels[2]

***Abstract*— The variable message signs, abbreviated as VMS messages, are disseminated through LED displays to provide the travelers and motorists information, warning and guidance on the current traffic situation. As an advanced traffic guidance system, the VMS messages help drivers to choose the routes with lower traffic volumes. Thus, the vehicles can be more evenly distributed in the road network to improve the performance of traffic system and reduce traffic delays. To this end, the VMS technology has been widely used in the expressways of Singapore. This paper aims to evaluate the immediate impact of VMS on the overall traffic distribution of Singapore in response to accidents and obstacles. For this purpose, we consider the incidents data and their corresponding VMS messages from the two busiest expressways of Singapore, namely Pan Island Expressway (PIE) and Central Expressway (CTE). For this analysis, we ignore the VMS messages of the locations which are already congested due to traffic incidents, since the motorists may be influenced by the congestion and not entirely by the VMS messages. The next step is to obtain the locations of other VMS displays and their nearby downstream exit points. The central argument of this analysis is that if the average traffic flow of the exits increases significantly compared to that of normal days, it demonstrates the impact of the VMS messages on the drivers' behavior. Our results show that the average outgoing traffic flow from the expressways towards the exits increases by 14% after the VMS messages have been activated.**

I. INTRODUCTION

Massive urbanization, growth in population, and economic development lead to a proliferation in traffic incidents and congestions in the roads of the metropolitans. For optimal utilization of the road network capacity and efficient traffic management during the incidents, the Land Transport Authority (LTA) of Singapore adopts Intelligent Transportation System (ITS), which provides an integrated solution for communication, control, and information processing in transportation. The LED road traffic signs alert the drivers about traffic congestion, accidents, incidents, or roadwork zones on a specific highway. These VMS messages are specifically designed to cater to Singapore's environment and traffic condition. Currently, the VMS displays designed to disseminate incidents information have been strategically distributed on the expressways of Singapore. Interest in the application of VMS in urban areas is very high at the moment in the world with many cities investing in new VMS systems. Borrough *et al.* and Lee *et al.* found that VMS messages can potentially reduce the number of crashes [14] [15]. Several studies evaluated the impact of the VMS message signs by observing the drivers' response to VMS messages in different countries.

According to a survey to measure the drivers' intent response to VMS messages along the freeways in Missouri, 94% of the investigated drivers answered that they followed the instructions and suggestions of the VMS messages [10]. Wang *et al.* also found that over 70% of the surveyed drivers claimed to be influenced by VMS message information [11]. Moreover, Ran *et al.* set a questionnaire for the drivers in Wisconsin to observe the drivers' response and obtained that about 70% of the drivers would change their route recommended by the VMS messages [12]. However, all these surveys were conducted by paper-and-pencil method, which highly depends on the willingness of the drivers to participate in the survey. Elham *et al.* conducted a phone survey in Los Angeles and concluded that around 70% of the interviewed drivers would divert to an alternative route if the messages provide enough information [13]. On the other hand, several studies carried out a field observation to understand the impact of VMS. Kiron *et al.* conducted a research on the impact of VMS messages in London using three stages of questionnaires and in the last step, they collected the responses based on two real-time incidents [1]. They noticed that the percentage of drivers who responded in favor of changing their routes in the first two stages was five times the percentage of drivers who actually changed their routes in the last stage. However, they did not calculate the actual number of cars that changed their direction during the incidents, instead they considered the responses provided by the drivers. Another field study in Oslo shows that there were approximately 20% of the cars which changed their direction as suggested by the VMS messages [5] [6]. However, they collected the data from two VMS sites and for two evenings only, which may not reflect the seasonal, temporal or spatial variations properly. Therefore, the size of the analyzed dataset is too small to come to any conclusion. Similarly, Taisir *et al.* observed in their field study on a major arterial of Saudi Arabia that only 5.9% of the drivers actually followed the instructions on VMS, which is only 7% of the total number of drivers who claimed to abide by the VMS [2]. However, they reported the results for only one VMS display, since there was no other VMS installed in the city where the research was conducted. Furthermore, they focused on only evening peak hours in their work.

In this study, we opt for a data-driven approach, since we have access to the historical datasets from the expressways of Singapore. Moreover, we have the VMS information

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collected from 70 displays from all over Singapore. Therefore, our analysis is not localized to any particular area of the city. In the following, we briefly summarize our main contributions in this work in comparison with the existing literature:

1) We apply a data-driven approach for analyzing the effect of VMS, which has not been attempted before. Therefore, our experiment is not biased by the false positive responses from the drivers, instead we compute the actual number of cars changing the direction in response to VMS messages.
2) Our dataset consists of 588 incidents with 1891 VMS messages recorded for two months. Moreover, it covers different categories, such as peak hour/off-peak hour incidents, types of incidents (accidents/obstacles), incidents on different highways (PIE/CTE), etc., whereas earlier studies lack this wide variety of incidents.
3) Moreover, we compare our results with that of other cities obtained by previous studies.

The remainder of this paper is organized as follows. In the next section, we describe our data set and the details of VMS messages. In Section III, we discuss the approach to our analysis, whereas we present our results in Section IV. Finally, in Section V we provide concluding remarks and ideas for future research.

II. DESCRIPTION AND ANALYSIS OF THE DATA

In this chapter, we describe the available raw data collected from the Land Transport Authority (LTA) of Singapore. The dataset considered in this study primarily comprises three types of data: (1) historical records of incidents, (2) the details of VMS messages, and (2) traffic data. We consider this data for two major expressways in Singapore (PIE and CTE), and for two months (September-October 2016). The expressways are divided into short road segments (of length 120 m on an average) labeled by unique link IDs.

A. Incidents Data

In the incidents data, we have the following attributes: (1) an incident ID which is unique to each accident, (2) the link ID where the incident happened with the respective coordinates, (3) the expressway and its direction along which the incident occurred, and (4) the start time and end time along with day and month of the incident. The incidents data studied in this paper comprises two types of incidents, i.e., accidents and obstacles. There are overall 588 incidents of these two types, where 90.48% of them are accidents. We show the distribution of the two types of incidents for the two expressways in Fig. 1.

B. Details of VMS Messages

There are in total 70 VMS displays on PIE and CTE in Singapore. The VMS data contains the following entries: (1) a unique VMS ID, (2) the activation time of the message, (3) the corresponding incident ID, (4) the location of the VMS display (i.e., the link ID where it is located), and (5) the information on the VMS signs. There were in total 1891 VMS messages recorded for 588 incidents. Usually, LTA activates most of the messages within few minutes after the incidents have been reported. Fig. 2 shows the histogram of the differences between the incident start time and the first activation time of the VMS. In the x-axis, 0 represents the start time of the incident. We find that for 96.6% of those 588 incidents, the first VMS messages were activated within 10 minutes after the incident starts. For the other messages, either the incident details were not immediately available or the incident did not affect traffic at the time of reporting. Therefore, the first VMS messages for those incidents were displayed only when the information was obtained or traffic lanes were closed, such as for incident recovery. Additional VMS messages which are located further away from the incident were displayed later, only when the congestion extended over time.

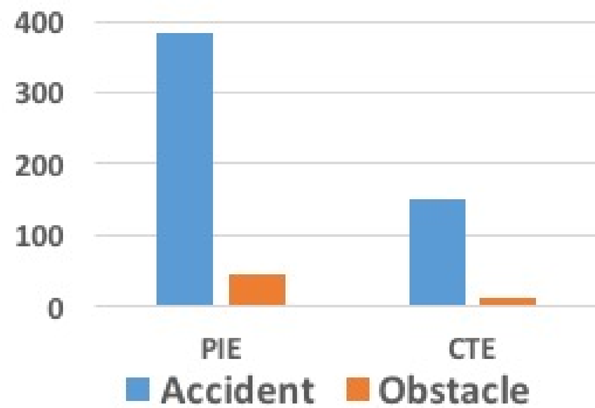

Fig. 1: Distribution of the incidents according to their types and expressways.

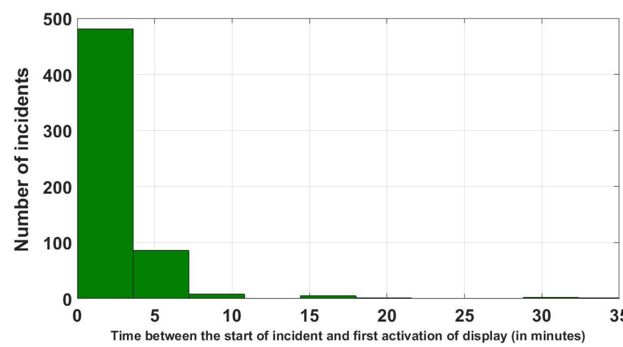

Fig. 2: Histogram of the differences between the incident start time and the first activation time of the VMS.

In addition, we have traffic data from the nearest upstream links of the exit points on the expressways in between VMS and incident locations. There are 72 exits on PIE and CTE. Fig. 3 shows the histogram of the distances between the VMS displays and their nearest downstream exit points. We observe in Fig. 3 that for 56% of the displays, the nearest exit is within 500 meter and in 92% cases, the distance is less than 1 km.

C. Traffic Data

The traffic data comprises link ID, the recording time, and the corresponding speed and traffic flow value of the

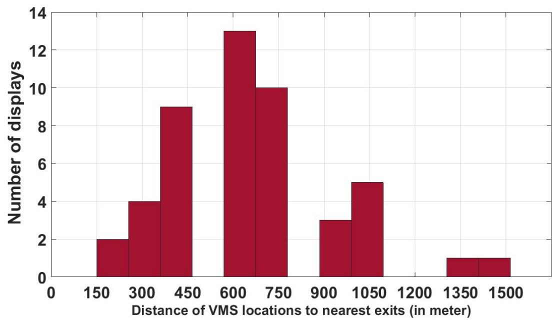

Fig. 3: Histogram of the distances between the VMS display locations and their nearest downstream exits.

expressways along with the exit points. The traffic flow and traffic speed values are recorded in each road segment at every five minutes interval. The speed value represents the average speed of all the vehicles that pass through that segment in the 5-minute span. However, the traffic speed data is in the form of speed bands. While the first nine bands represent speeds up to 90 kmph (each spanning 10 kmph), the 10-th band corresponds to the speed higher than 90 kmph. On the other hand, the flow value indicates the number of cars passing through that road segment in 5 minutes span and the unit of flow data is vehicles per hour.

III. Analysis

In this section, we explain how we evaluate the effect of VMS messages. We show a schematic diagram of the incident and VMS message locations in Fig. 4. Let us assume

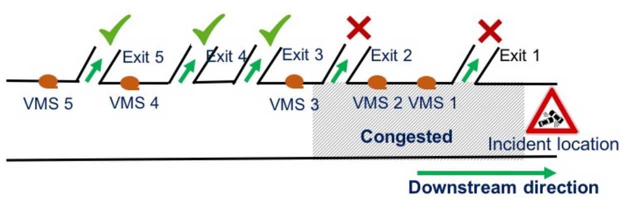

Fig. 4: A schematic diagram of the road with exits and VMS message locations.

that an incident happened at time t_{start} on one Monday at link ℓ and the activation time of the VMS messages $V_1, V_2, \ldots, V_n$ is $T_1, T_2, \ldots, T_n$ respectively, where $T_{\text{j}} >= t_{\text{start}}$ for $j = 1, \ldots, n$. Moreover, we suppose that the VMS displays are located at the links $\ell_1, \ell_2, \ldots, \ell_n$ respectively. Now, we explain the steps of our analysis as shown in Fig. 5. We start our analysis from the time instant T_{min} when at least one of the n VMS messages has been activated, i.e. $T_{\text{min}} = \min(T_j)$, where $j = 1, \ldots, n$. At a particular time instant T, first we select one VMS that was already activated, say V_j and find the upstream links nearest to the exit locations $E_1, E_2, \ldots, E_m$ in between the VMS display location ℓ_j and incident location ℓ. Next, we examine if the exits E_k, where $k = 1, \ldots, m$ are congested or not using the traffic data. This step is important prior to analyzing the impact of VMS because if the exit is located along a congested stretch of the expressway or the exit ramp itself is congested, there are two possibilities:

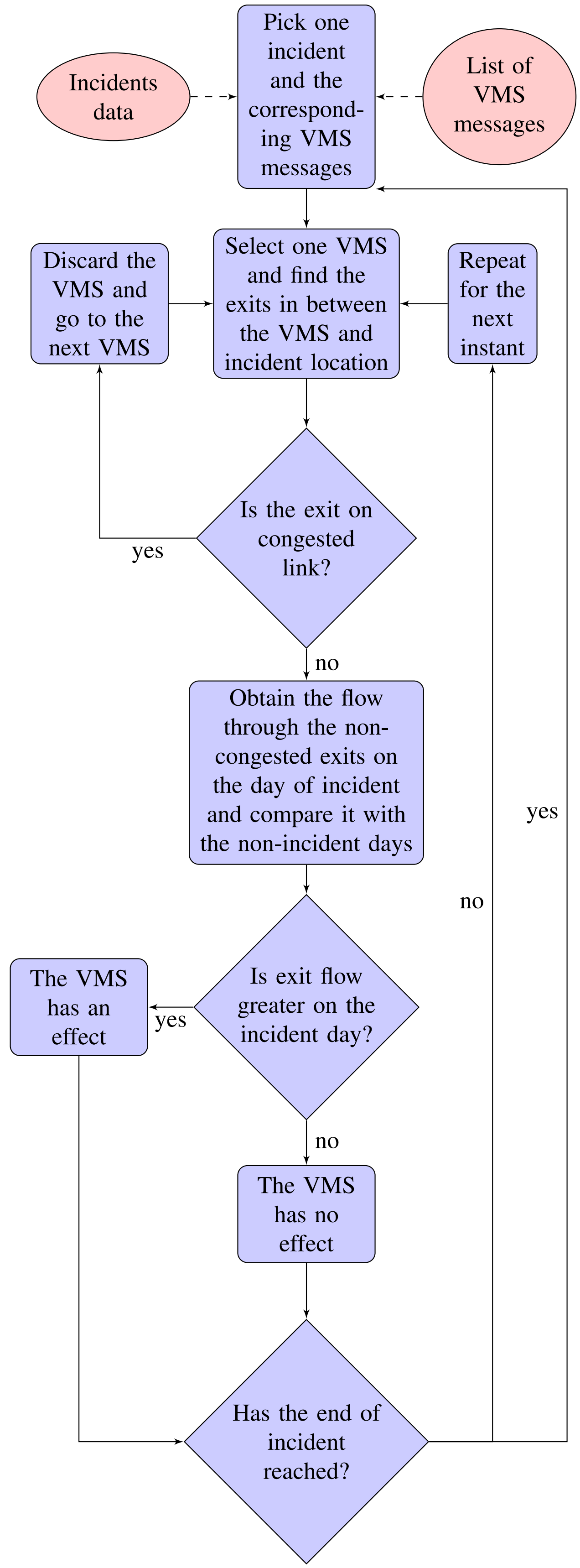

Fig. 5: Flow-chart of our approach.

(1) the cars are stuck in the congestion, hence the drivers may not be able to leave the road through the exit. (2) If the driver somehow manages to escape from the congestion and drives through the exit, still we can not conclude that the driver changed his direction seeing the VMS, rather he may have changed the route seeing the congestion itself. Therefore, we compute the average speed and flow of the same exit link E_k at time T of non-incident Mondays (as the incident happened on one Monday) and calculate the differences of the traffic data recorded on the day of incident with this average of non-incident days. Let us assume that the traffic speed in link E_k at the time instant T on the day of incident is $s_{E_k,T}$ and on non-incident Mondays are $s_{E_k,T_{M_1}}, \ldots, s_{E_k,T_{M_p}}$, assuming there are p Mondays in the two months September-October 2016. Hence, for link E_k at time instant T, the speed difference is given by:

$$d_{s_{E_k,T}} = s_{E_k,T} - \frac{s_{E_k,T_{M_1}} + \ldots + s_{E_k,T_{M_p}}}{p}. \quad (1)$$

Similarly, we compute the flow difference $d_{f_{E_k,T}}$ in the link E_k at time instant T. Now, we consider the link E_k to be congested if both traffic speed and flow are lower on the day of incident compared to the average of non-incident days, i.e. $d_{s_{E_k,T}} < 0$ & $d_{f_{E_k,T}} < 0$. Thus, we determine if the exits $E_1, \ldots, E_m$ are congested or not at the time instant T. Although the data of non-incident days is varied, we consider the average of non-incident days as the threshold for comparison purpose to alleviate the effect of recurrent or peak-hour congestion. In the similar way, we can also determine whether the adjacent expressway links are congested or not. If all the exits are congested, we discard that VMS and choose the next active VMS at that instant. Otherwise, we proceed to the next step, i.e. analyzing if the VMS has any effect or not.

For that purpose, we consider the change in outgoing traffic flow from the expressway to the individual exits. Let us assume that the traffic flow in link E_k at the time instant T on the day of incident is $f_{E_k,T}$ and on non-incident days are $f_{E_k,T_{M_1}}, \ldots, f_{E_k,T_{M_p}}$. We compute the median, i.e., 50-th percentile of the flow values of non-incident days and denote it as med $(f_{E_k,T})$:

$$\text{med}\,(f_{E_k,T_M}) = \text{median}\,(f_{E_k,T_{M_1}}, f_{E_k,T_{M_2}}, \ldots, f_{E_k,T_{M_p}}). \quad (2)$$

Next, we determine the flow difference for link E_k at time instant T as given by:

$$D_{f_{E_k,T}} = f_{E_k,T} - \text{med}\,(f_{E_k,T_M}). \quad (3)$$

Ideally, the average traffic flow in the exit link on the day of incident should exceed that of normal day, i.e., $D_{f_{E_k,T}} > 0$ if there is an effect of VMS. However, we compute the fractional change in traffic flow due to the VMS messages and denote it as flow change ratio (FCR):

$$FCR = \frac{D_{f_{E_k,T}}}{\text{med}\,(f_{E_k,T_M})}. \quad (4)$$

We consider a VMS to have an impact if FCR is greater than 0 for at least one exit. We discard those exits where FCR is less than 0 and compute the average of FCR of all other exits to obtain the final result.

In this way, we perform the analysis at an interval of 5 minutes until the incident ends. When the end of the incident is reached, we pick another incident and repeat all the steps.

IV. RESULTS

In this section, we show the results of our analysis and based on that, we deduce if the VMS system has a significant impact or not in the Singapore road network.

A. Analysis of the Impact of VMS

We first show the variation in average flow change ratio (FCR) with elapsed time in Fig. 6 since the activation of VMS. The x-axis in Fig. 6 represents the elapsed time in minutes, where $x = 0$ represents the activation time of the messages. The VMS messages have been aligned at $x = 0$ based on their activation time. Therefore, the negative x axis represents the time before the activation of the messages. Our main objective is to compare the flow change ratio before and after the activation of VMS, therefore we consider since 25 minutes before the messages were activated.

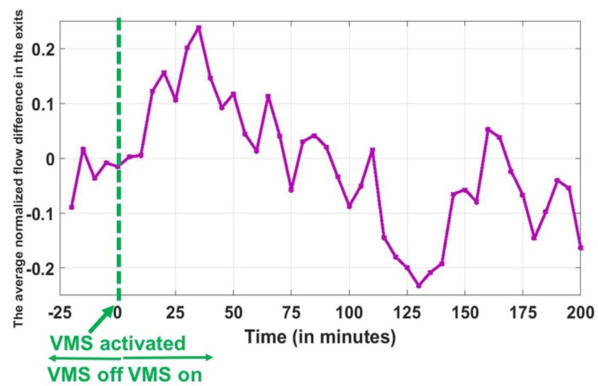

Fig. 6: The variation of average flow change ratio (FCR) with time averaged over all incidents.

We observe in Fig. 6 that there exits a sharp positive slope in the FCR graph after $x = 0$. Therefore, we can conclude that overall there is an impact of VMS. Secondly, the value of FCR is not positive immediately after $x = 0$, rather it increases after $x = 10$, which is very obvious because after seeing the VMS message, the drivers take some time to travel to the nearest exit. Last but not the least, the maximum value of average FCR in the graph is 0.24. Therefore, at a particular time instant, on an average the traffic flow leaving through the exits may increase by upto 24% compared to normal days. The mean FCR before and after activation of VMS is -0.05 and 0.09, respectively. Therefore, the FCR increases by 14% after activation of VMS.

Next, we show the histogram of average FCR for all incidents in Fig. 7. For this purpose, we first determine the exits and the durations when FCR is greater than 0 in those exits. Further, we average the FCR over the entire duration

TABLE I: Summary of the results obtained by previous studies.

Literature	Method of data collection	Percentage of positive response
Praveen *et al.* [10]	Motorists' survey in Missouri	94% of the surveyed drivers
Wang *et al.* [11]	Questionnaire survey in Rhode Island	70% of the participated drivers
Ran *et al.* [12]	Questionnaire survey in Wisconsin	70% of the participated drivers
Elham *et al.* [13]	Phone survey in Los Angeles	70% among the called drivers
Kiron *et al.* [1]	Both questionnaire and field observations in London	Positive response in the survey is 5 times the actual number
Alena *et al.* [5]	Field study in Oslo	20% of the cars changed direction
Taisir *et al.* [2]	Both questionnaire and field observations in Saudi Arabia	5.9% driver changed direction, 85% positive response in survey
Our work	Historical data	14% driver changed direction

for the individual exit. Finally, we obtain the histogram of the incidents as shown in Fig. 7 by averaging the values of FCR over all exit points corresponding to each incident.

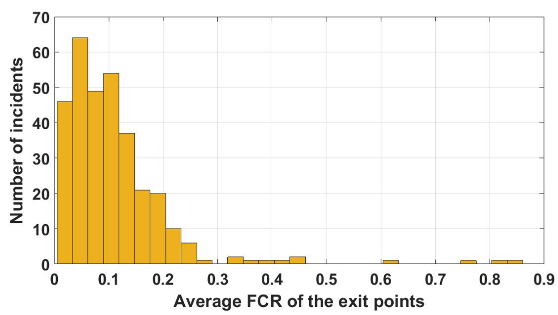

Fig. 7: The histogram of average flow change ratio (FCR) of all incidents.

We now compare our result to the existing literature in Table I and analyze if the impact of VMS in Singapore is comparable to other cities. We observe in Table I that most of the studies presented their results based on the participating drivers' responses, where the participation rate is very unlikely to be 100%. Moreover, the participants may respond positively in the surveys whereas in practice, they are reluctant to follow the messages. On the contrary, our results are free from the response biases. In fact, the previous studies compared the results obtained by the questionnaires and field observations and found that the positive response rate in the survey differs significantly from the actual change in traffic flow [1] [2]. Therefore, although the percentage of positive response is low in the field observations as well as in our study, the results are more accurate.

B. Comparative Analysis of the Results for Different Categories of Incidents

In this subsection, we present a comparative analysis of our results for different categories of incidents based on their features. First, we plot the similar graph in Fig. 8 as in Fig. 6, however for the incidents of PIE and CTE separately. We find in Fig. 8 that the value of average FCR is in general higher for PIE compared to CTE at any particular time instant. Since PIE is longer than CTE, it is more likely that more VMS messages can be displayed upstream of an incident, therefore the motorists are better informed. Besides, PIE has more exits, hence there are more alternatives available to the drivers.

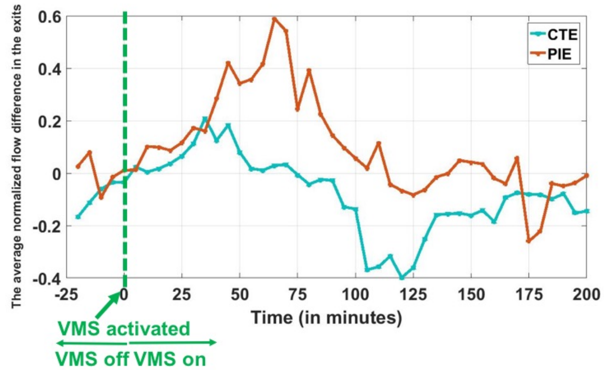

Fig. 8: The variation of average flow change ratio (FCR) with time for the incidents in PIE and CTE.

Next, we plot the FCR graphs for peak hour and off-peak hour incidents separately in Fig. 9. We observe in Fig. 9 that the values of average FCR are higher for off-peak hour incidents compared to that of peak hour incidents. For peak hour incidents the maximum value of average FCR is around 20%, whereas for off-peak hour incidents it is close to 37%. Therefore, the impact is more significant for off-peak hour incidents. This is because in peak hour most of the roads experience heavy traffic, hence motorists may choose not to divert.

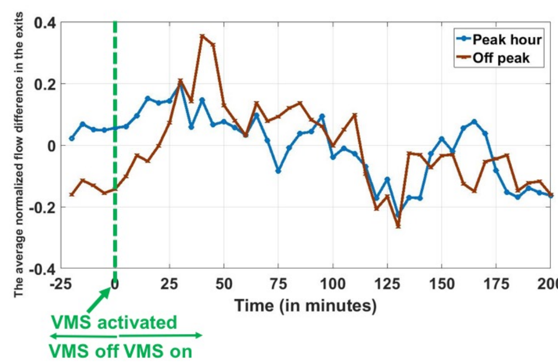

Fig. 9: The variation of average flow change ratio (FCR) with time for the peak hour and off-peak hour incidents.

Besides, the type of incident is also an important feature. Therefore, we show the FCR plot with time in Fig. 10 for accidents and obstacles separately. In Fig. 10, the FCR curve for accidents is quite similar to Fig. 6, whereas there is not much variation in the FCR curve for obstacles. Since the obstacles only cause partial closure of the lanes, the overall capacity of the roads remain relatively unaffected. Furthermore, the average FCR value is significantly high at the higher duration range for accidents since the average duration of accidents is longer than that of obstacles.

Finally, we compare the mean and median values of the FCR averaged over all exits for different categories of incidents in Table II.

TABLE II: Mean and median of FCR averaged over all exits for different categories of incidents.

		Time		Expressway		Type of incident		All together
		Peak hour	Off-peak	PIE	CTE	Accident	Obstacle	
Before VMS is activated	Mean	0.023	-0.13	0.02	-0.15	-0.06	-0.13	-0.056
	Median	0.01	-0.17	-0.01	-0.17	-0.07	-0.17	-0.07
After VMS is activated	Mean	0.068	0.17	0.31	0.02	0.36	-0.014	0.092
	Median	0.028	0.11	0.21	-0.01	0.33	-0.1	0.052

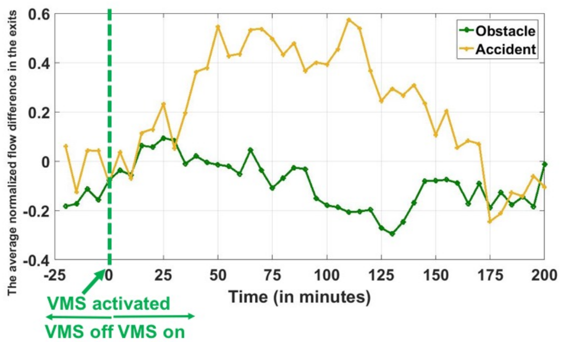

Fig. 10: The variation of average flow change ratio (FCR) with time for accidents and obstacles.

V. CONCLUSIONS

In this paper, we aimed to investigate the impact of VMS messages on the traffic conditions of the expressways in Singapore. To this end, we analyzed traffic incidents and VMS data from the two most crowded expressways of Singapore. Our results show that on an average the value of FCR increases from -5.6% to 9.2% with elapsed time. Therefore, the VMS messages can effectively inform the drivers on the roads about the route guidance and significantly improve congestion avoidance.

However, in this project, we have used traffic flow data for analyzing the impact of VMS, whereas the total number of vehicles would have been a better metric for this purpose. Moreover, there might be other sources to broadcast the information about the incidents, like radio channels, Internet, etc. Therefore, understanding the impact of VMS based on historical records is a rather convoluted task. Lastly, since VMS technology is still in its nascent stage, the awareness among drivers and thereby, the effectiveness of these messages as a traffic guidance tool is significantly less than optimal. With growing recognition for the efficacy of VMS technology, we hope to see significant increase in the impact of VMS on overall traffic conditions in coming years. Moreover, it would be very interesting to expand the analysis by incorporating the impact of information dissemination through V2X in future work.

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REFERENCES

[1] Chatterjee, Kiron, N. B. Hounsell, P. E. Firmin, and P. W. Bonsall. “Driver response to variable message sign information in London.” Transportation research part C: Emerging technologies 10, no. 2 (2002): 149-169.

[2] Taisir Ratrout, Nedal, and Yazan F Issa. “Effectiveness of newly introduced variable message signs in Al-Khobar, Saudi Arabia.” PROMET-Traffic & Transportation 26, no. 2 (2014): 169-177.

[3] Yan, Xuedong, and Jiawei Wu. “Effectiveness of variable message signs on driving behavior based on a driving simulation experiment.” Discrete dynamics in nature and society 2014.

[4] Schroeder, Jeremy L., and Michael J. Demetsky. “Data analysis of diversion and dynamic message signs.” Journal of transportation engineering 137, no. 9 (2011): 608-614.

[5] Erke, Alena, and Fridulv Sagberg. “Effects of Variable Message Signs (VMS) on driver attention and behaviour.” Association for European Transport (2006).

[6] Cummings, M. “Electronic sign strategies and their benefits.” (1994): 141-144.

[7] Dos Santos, Cristina. “Assessment of the Safety Benefits of VMS and VSL using the UCF Driving Simulator.” (2007).

[8] He, Shuyan, and Wei Guan. “Evaluation of the effects of variable message signs at urban traffic network.” In Industrial Technology, 2006. ICIT 2006. IEEE International Conference on, pp. 2955-2959. IEEE, 2006.

[9] Shang, HuaYan, HaiJun Huang, and ZiYou Gao. “Impacts of variable message signs on traffic congestion.” Science in China Series E: Technological Sciences 52, no. 2 (2009): 477.

[10] Edara, Praveen, Carlos Sun, Clay Keller, and Yi Hou. “Evaluating the benefits of dynamic message signs on Missouri’s rural corridors.” No. cmr 13-004. Missouri. Dept. of Transportation, 2011.

[11] Wang, Jyh-Hone, Charles E. Collyer, and Chun-Ming Yang. Enhancing motorist understanding of variable message signs. Rhode Island Department of Transportation, Research and Technology Development, 2006.

[12] Ran, Bin, Bridget Barrett, and Emily Johnson. “Evaluation of variable message signs in Wisconsin: Driver survey.” No. Report No. 0092-45-17,. 2004.

[13] Shirazi, Elham, Stuart Anderson, and John Stesney. “Commuters’ Attitudes toward Traffic Information Systems and Route Diversion.” No. 1168. 1988.

[14] Borrough, P. “Variable speed limits reduce crashes significantly in the UK.” The Urban Transportation Monitor (1997).

[15] Lee, Chris, Bruce Hellinga, and Frank Saccomanno. “Assessing safety benefits of variable speed limits.” Transportation research record: journal of the transportation research board 1897 (2004): 183-190.

[16] Edara, Praveen, Carlos Sun, Clay Keller, and Yi Hou. “Evaluation of dynamic message signs on rural freeways: case study of a full freeway closure.” Journal of transportation engineering 140, no. 1 (2013): 89-98.