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ROAD USERS PERCEPTION OF DYNAMIC MESSAGE SIGNS AND LANE CONTROL SIGNS

BY

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ABSTRACT

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The state of Qatar is continuously developing and has been capitalizing enormously in upgrading transportation. The latest upgrade in transportation was the introduction of Intelligent Transportation Systems (ITS). Qatar has invested in building an infrastructure for ITS and installing many of its systems, including the Dynamic Message Signs (DMS) and Lane control signs (LCS). These signs have been installed in multiple areas in the city of Doha, the capital of Qatar. However, there have not been many studies in the region about the effectiveness of such system on the driver behavior. The first aim of this study is to capture the public opinion of DMSs in Qatar. The second aim is to evaluate and compare driver behavior between different type of roads and the impact of DMS and LCS on driving behavior. Two methods of data collection were used in this study, an online survey of 402 participants, and a real-life driving experiment of 32 participants in a defined route in Doha city that consists of three sections; arterial roads, freeway with electronic signs, and freeway without electronic signs. Descriptive and hypothesis analysis were conducted. There are number conclusions resulted from the analysis. According to the survey results, most participants find the DMS useful, and are likely to follow the instructions especially for warning messages about construction works and road conditions. With regards to driver behavior, it was found based on the driving experiment results that driver compliance is increased when ITS signs are deployed. Journey comfort is also found to be increased when ITS is implemented.

DEDICATION

I am dedicating this thesis to Almighty Allah. Alhamdulillah and Thank God for giving me guidance, strength, and a healthy life. Also, to beloved people who have meant and continue to mean so much to me. To my dear wife and daughter who have been a source of inspiration and encourage me when I thought of giving up. To my parents, brother, sister, relatives, friends, and classmates who advised and encouraged me to finish this study. And lastly, to my advisor and professors in Qatar university who I have learned so much from them and I cannot be thankful enough

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Qatar is considered one of the highest countries with number of deaths due to traffic accidents. Shaaban (2012) Shaaban (2012) compared Qatar to United States and United Kingdom in number of deaths per 100,000 population and found that Qatar is the highest with 23.7, followed by US with 13.9, and followed by UK with 5.4. The number however, is reduced to 15.2 per 100,000. This is due to different reasons such as the huge increase of population in Qatar which from 840K in 2007, to 1.9 million in 2013, and to 2.7 million in 2019 (Shaaban & Hassan, 2014) and aggressive driver behavior (Shaaban, Muley, & Mohammed, 2018; Shaaban, Wood, & Gayah, 2017).

The public roads agency in the state of Qatar, known as Ashghal or Public Works Authority, is always looking for ways to improve traffic safety and overall road user satisfaction in Qatar. Ashghal has started an Intelligent Transportation Systems (ITS) program in 2011. The objective of the program is to develop a State-wide ITS Architecture and Master Plan that incorporates all modes of transportation. The primary purpose of this ITS Master Plan is to develop a comprehensive strategy setting the direction and pace of ITS investments within the State since the last 5 years and beyond. This project also includes the development and deployment of a broad-based ITS infrastructure within the State of Qatar with the following objectives:

(a) Developing an efficient multi-modal transportation network;

(b) Building an inclusive transportation infrastructure that will support and future requirements

(c) Ensuring national recognition of the state of Qatar as a developed state with the latest technologies in transportation.

(d) Enhancing traffic safety by reducing traffic accidents and secondary accidents, improving survival rates.

(e) Improvements on the environment and air quality by reducing greenhouse gas emissions.

(f) Improve traffic movements by reducing congestion and journey time and providing road users with a reliable and trusted real time traffic information.

(g) Improve public satisfaction

The program includes different systems that will be able to detect, monitor and control the traffic, while providing the road users with information that will increase the safety of the roads and reduce the traffic congestion. According to Ashghal ITS Deployment Guidelines V2.2, the ITS in Qatar will include the following but not limited to systems:

- Traffic Detection and Monitoring Systems
- Closed Circuit Television Cameras (CCTV)
- Roadway Weather Information and Air Quality Monitor Systems
- Over-Height Vehicle Detection System
- Over-Weight Vehicle Detection System
- Dynamic Message Signs
- Lane Control Signs
- Ramp Metering Systems (Ashghal, 2019)

These systems will be integrated with each other to work simultaneously in detecting data and providing information to the traffic management center and to the public.

The implementation of ITS systems in Qatar comes with a high cost as the infrastructures need to be upgraded in order to connect the devices to control rooms, data centers, etc., in addition to the cost of the actual devices. The ITS program is currently in implementation stage. However, there have not been many studies in the region about the impact of such system on the driver behavior. Hence this study will focus on two of ITS systems, DMS and LCS. The ITS program in Qatar is currently deploying DMS and LCS with more than twenty DMS currently operating, and 1 corridor where LCSs are deployed. These numbers are expected to increase significantly in the near future as the expressway program of Qatar is being completed.

1.1 DYNAMIC MESSAGE SIGNS

Dynamic Message Signs (DMS) are electronic screens that are placed above or on the side of the road and can view characters along with pictures in motion. They are also called Variable Message Signs (VMS). There are many applications and usage of DMS in which the road agency can decide on. They can be used to view weather updates, road conditions, or as a warning sign. DMS basically provide the road users with information that they can use on their journey to take smart decisions that will result in a safer, or shorter travel time. Although DMS can be used to present non-traffic information such as special event celebrations or advertisements, it is not recommended to be used for such purpose as it may distract the drivers and result in accidents. Another reason why this is not recommended is the fact that when users get used to non-traffic usage of these screens, they may ignore them when there is a real traffic situation.

There are many different sizes of DMS screens and mounting locations that differ based on the application of their usage. They can be placed before intersections to give the users alternative routes based on road conditions, or a long a road segment that will give drivers information about the travel time or road conditions. They can be also used to alert drivers on over-height, over-weight or speeding. Figure 1 shows an example of DMS used in Qatar.

Figure 1, Example of a DMS used in Qatar

1.2 LANE CONTROL SIGNS

Lane Control Signs (LCS) are small electronic signs placed specifically for each lane on the road. Their sizes vary and can be used on open roads or inside tunnels. Information showed on LCS are typically maximum allowed speed (similar to posted speed limit signs) or the status of the lane (open, closed, or merge). LCS can also be used to implement variable speed limit (VSL). However, VSL is currently not implemented in Qatar but is considered to be in the future. An example of LCS signs mounted on a gantry and collocated with directional signs is shown in Figure 2.

Figure 2, Example of LCS used in Qatar

1.3 THE RESEARCH PROBLEM

There have been many studies on the impact of DMSs and LCSs on traffic safety and traffic congestion in different countries, but limited studies were conducted in Gulf Cooperation Council (GCC) countries. The state of Qatar has invested millions of Qatari Riyals on implementing DMSs and there is no solid evidence that this will improve the roads usage. This research will study the road user perception of DMSs and driver behavior when DMS or LCS are implemented.

1.4 THE RESEARCH QUESTIONS

Below are some of the research questions that expected to be addressed by the end of the study:

- How will the drivers react to information provided by a DMS?
- What are the types of messages that are more followed and what messages are less followed by drivers?
- What is the public opinion of DMSs in Qatar?

- What is the impact of DMS and LCS on lateral position and lane changing of drivers?
- Does implementing DMS and LCS have impact on driver speed?
- What is the impact of DMS and LCS on journey comfort?
- Do drivers follow the different traffic signs used on the roads?

CHAPTER 2: LITERATURE REVIEW

Literature review is divided into six sections. Section 1 discusses the results found in previous study on the impact of DMSs on driver behavior. Similarly, Section 2 discuss the impact of LCSs on driving behavior. Section 3 will review data collection methods that was used in previous studies and the methods of analysis. In this study, two methods of data collection will be used; online survey and driving experiment. Section 4 will discuss survey design questions and number of participants used in past studies. Section 5 will discuss many elements of the driving experiments as per previous studies including number of participants, validity of participants' self-reported data, time of the day, and the variables collected from the experiment. Finally, Section 6 summarizes the literature review and provides some conclusions.

2.1 THE IMPACT OF DMS ON DRIVER BEHAVIOR

Many studies have focused on the topic of road users' perception of DMSs. It is important to identify if the implementation of such signs did have any effect on driver behavior. This section will review several studies how people will react to certain messages and in certain situations.

Rama and Kulmala (2000) Rämä and Kulmala (2000) conducted a field study to investigate the effects of two DMSs on driver behavior. The study was performed in Finland at three sites. The before-and-after experiment was conducted two winter seasons. Two types of DMS signs were evaluated; a slippery road condition and minimum headway between vehicles. Results showed that some type of signs reduced the average speed on slippery roads by 1 km/h. Additionally, other type of signs, i.e., minimum headway sign, has decreased the proportion of headways shorter than 1.5 seconds.

Dutta, Fisher, and Noyce (2004) used a driving simulator to study the effect of DMS obstructions on driver performance. This research studied the obstructions of DMS that is caused by traffic or road geometry; the sequence of a two-phase message is presented to the driver; the message content; and lane changes occurrences and direction of lane changes that is required by the driver by the DMS. This study evaluated drivers' performance based on two different message durations. There are several conclusions that are taken from the results of the analysis. It is recommended based on the results of this study to repeat biphasic messages in the legibility zone.

Lai (2010) combined field measurement and survey in their study which presented an ergonomic study on the message design of DMS signs on urban roads in Taiwan. This study investigated the effects of color schemes (one, two and three) and also, the number of message lines (single, double and triple) of DMS on drivers' performance. The study used a laboratory experiment and a post-experiment preference survey. Results of analysis showed that using two colors will be more beneficial to driver's response time than using one or three colors. Additionally, it was found that using double line message has better response time than using a single- or three-line messages. Finally, based on the results of the post-experiment preference survey, it was found that drivers preferred two-color scheme with double line messages than any other combination.

Guattari, De Blasiis, and Calvi (2012) studied the effectiveness of DMS messages on driving behavior. The study used a driving simulator called STI for data collection. The driving simulator used different scenarios of the road and signs. For example, the road had different geometries, traffic condition and road environment. The simulated route was based on a real road in Italy. The signs had different sizes and messages. The experiment first made the driver familiar with the simulation system by giving a 10 min training session, followed by the actual experiment that is 20 minutes long. One thing the experiment used is to give drivers brake after each scenario, so it will remove the driving fatigue. The results show that there are major differences in driving behavior depending whether the driver understood the message or not. If the message is not understood, results showed that a 5% decrease in driver's speed profile, while the speed remained stable when drivers understood the message. Furthermore, the pressure on accelerator pedals have been recorded and found that the pressure is always decreasing when the driver is approaching the sign but increase when the driver understands the sign and remain decreasing if the sign was not understood. The outcome of this study is that DMS can help drivers take good early decision when the message is understood, but can have negative effect if the driver did not understand the message.

Er-hui, Jing, Yun-ling, and Juan (2013) studied drivers' response to different graphical images in DMS. This study used three different sets of graphical images in a questionnaire to evaluate drivers' response. Results showed that drivers' selection of different graphical images had substantial differences. Based on analysis of this study, this study provides a model for selection of graphical images in DMS design.

Ma, Shao, Song, and Chen (2014) investigated driver response attitudes towards DMS provided information. This study conducted a survey to obtain the information. The survey includes thirteen questions and divided into four parts: Personal socioeconomic characteristics, trip characteristics, driver's perception of the DMS message, response to the displayed message. This study had a number of conclusions. With regards to personal socioeconomic characteristics, it was found that females, higher driving age, drivers of private vehicles, and calm drivers, are more likely to respond to the message instruction to divert to an alternative route. Similarly, with regards to trip characteristics, commuters and more familiar of the route drivers are more likely to divert to an alternative route. Regarding driver's attitude and perception towards DMS message content, most drivers agree that the DMS provides valuable information. On the aspect of DMS displayed information, it was found that drivers are more likely to divert to an alternative route if the alternative route is medium in size. Also found that most drivers prefer pictograms or graphical message than normal character messages.

M. Li, Lin, He, and Jiang (2016) investigated the impact of the travel time display on DMS on drivers' route choice behaviors. The study developed a stochastic network equilibrium model with the travel time information displayed using DMSs. The results of this study provided a paradox where increasing the accuracy of travelers' perception for travel times leads instead to degradation in the network performance. It is concluded based on the results that best design of DMS locations and travel time display can provide mitigations to reduce congestion.

Ronchi, Nilsson, Modig, and Walter (2016) investigated the design of DMS as information provided for road tunnel emergency evacuations. This study evaluated 17 DMS sites using a questionnaire. The study provided recommendations on the characteristics of the DMS systems. Recommendations included: using larger DMS screens, using flashing lights, and combining text and symbol for emergency exit sign.

Wu and Liang (2017) produced a model to determine best locations for DMS based on drivers' perception. The optimum location for a DMS is where the sign can reduce travel time. Similarly, a misplaced DMS may increase travel time. The research methodology used survey both online and field surveys to record drivers' satisfaction with the DMS. This research used the satisfaction rate in order to determine the compliance rate using a method of conversion. This due to the fact that DMS messages are not mandatory to follow, so it is hard to determine the compliance rate of drivers to the DMS message. The selection model for DMS was based on drivers' responses to the survey where their satisfaction degrees to DMS-based information service is proposed to minimize the total travel time. Finally, a case study was conducted to verify the model. The study indicated that as drivers' compliance rate increase, the total travel time decreases.

Zavareh, Mamdoohi, and Nordfjærn (2017) measured the drivers' behavioral based on DMS messages that indicated the risk levels. In this study, three levels of risks were indicated; low, medium, and high. The study measured the implications of each message that includes; speed, time to collision, and safety margin. Results showed that the same message may have different implications in different situations. The effect of high-risk messages was always related to safe adaptations. Based on the results of this study, it can be concluded that DMS messages can affect driver behavior especially when informed of high-risk situations.

Harms, Dijksterhuis, Jelijs, de Waard, and Brookhuis (2018) assessed the effect of using traffic irrelevant messages by studying the driver behavior with response to a critical route instruction displayed on a DMS that previously displayed different traffic-irrelevant messages. Results show that drivers that were informed of a critical route instruction had a compliant driver behavior in the experimental group. Drivers did however reduce the speed which was to increase the time they needed to process the DMS message. However, the control group reduced the speed much harder. The conclusion of this study is that if the DMS provided traffic-irrelevant messages, it will not affect the traffic management. Compliance behavior, Driver comments, recall and recognition, and speed were used as variables in this study.

Xu, Zhao, Chen, Bian, and Li (2018) investigated the effects of DMS control strategies on driver behaviors. This study also reviewed the effect of DMS's message content and location on driving safety in work zones. This study used a driving simulator and a questionnaire to validate simulator outcomes. Results show that the control strategies have a substantial effect on driver behavior variables such as; speed, acceleration, and lateral placement. All different control strategies resulted in speed reduction, increased compliance, and improved driving stability.

A summary of literature review on DMS impact on driver behavior is shown in Table 1.

Table 1, Summary of literature review on driver behavior with DMS

Author	Year	Main conclusion
Rama, P and Kulmala R	2000	This study concluded that the DMS messages has positive effect on driver's speed and headway distance.
Dutta et al.	2004	The study provides a recommendation to the DMS message content design to repeat biphasic messages in legibility zone
Lai, C	2010	Results show that participants prefer two-color, double line than other combinations
Guattari et al.	2012	The outcome of this study is that understanding the message will help drivers in taking good decision
Er-Hui et al.	2013	This study concluded provided a model for graphical design of DMS's pictograms.
Ma et al.	2014	The study concluded the following; females, higher driving age, private vehicles drivers, commuters, and calm drivers are more likely to follow DMS message. Also, drivers prefer pictograms than text, and more likely to follow alternative route if the route is medium in size.
Li et al.	2016	It is concluded based on the results that optimal design of DMS locations and travel time display can provide mitigations to reduce congestion.
Ronchi et al.	2016	The study provided recommendations on the characteristics of the DMS systems. Recommendations included: using larger DMS screens, using flashing lights, and combining text and symbol for emergency exit sign.

Author	Year	Main conclusion
Wu, Z. and Liang, Y.	2016	This study developed a DMS location selection model that is based on drivers' responses to schematic DMS designs.
Zavareh et al.	2017	Results showed that the same message may have different implications in different situations. The effect of high-risk messages was always related to safe adaptations.
Xu et al.	2018	The study concludes that the control strategies have a major effect on drivers' decisions, behavior and compliance.
Harms et al.	2018	This study concluded that traffic-irrelevant messages provided by a DMS will not affect traffic management.

Based on previous studies, it is noted that DMS have positive impact on driver behavior and speed. Previous studies highlighted drivers' preference of using two colors, double line, large DMS screens, flashing lights and combining text with pictograms. Also, some socioeconomic parameters effect drivers' decision to follow DMS. Lastly, providing traffic-irrelevant messages on a DMS will not affect traffic management.

2.2 IMPACT OF LCSS ON DRIVER BEHAVIOR

LCSs is another type of signs that appears similar to DMS. However, the functions vary significantly. This section will summarize the findings of three studies on the impact of LCS on driving behavior.

Schaefer, Upchurch, and Ashur (1998) analyzed the percentage of drivers complying with LCS using a simulation model. The model in this study used one direction of a 3-lane freeway. The model also had assumptions regarding the length of the vehicle, minimum acceptable headway, definition of compliance and the road network. Delay was used as the measure of performance for the freeway system. The model also used different flow rates; low, medium, and high. Later on, the study included further flow rates as the three flow rates were not enough for conclusion. Results show that LCS has low influence on traffic congestion in heavy, medium, and low traffic conditions. Heavy traffic conditions had no change even if drivers fully comply with LCS. Similarly, LCS had no effect on low, or medium traffic levels. However, at medium to high range, specifically at a flow rate of 1150 vphpl, and at 70% compliance, lane control was found to be effective.

Wang, Chang, and Ioannou (2009) used Microscopic simulator VISSIM for the design and evaluation of the LCS signs. The study used sixteen incident scenarios with four varying factors: demanding flow, incident duration, incident location and driver compliance rate. The effectiveness of the LCS systems were evaluated based on average speeds and average number of stops per vehicle from one-hour simulation runs. Results show that LCS can help decreasing the number of stops for vehicles for high compliance rates. Low compliance rates however will not have any impact. In conclusion, drivers need to comply with LCS to be beneficial and hence, LCS should be integrated with other systems such as speed control or enforcement.

Zhang and Ioannou (2017) investigated the effect of combining ramp metering with LCS and VSL on traffic mobility. The three systems have been coordinated to establish traffic flow stability and improvements on traffic mobility and traffic safety. The study used microscopic simulator VISSIM to carry out Monte Carlo simulations to evaluate the performance for the combined three systems. Results show significant improvements on stability of the traffic flow, as well as, mobility, safety, and environment.

Table 2, Summary of literature review on results of driver behavior with LCS

Author	Year	Main conclusion
Schaefer et al.	1998	No influence on heavy traffic conditions For medium traffic conditions, LCS had positive effect.
Wang et al.	2009	Positive impact on the environment and safety for high compliance rate.

Author	Year	Main conclusion
Zhang & Ioannou	2017	Significant improvements on stability of the traffic flow, mobility, safety, and environment.

Based on previous studies, it is concluded that LCS have positive effect on traffic flow and road safety. However, LCS will have effect only on low to medium traffic conditions but will not be beneficial on heavy conditions.

2.3 DATA COLLECTION AND ANALYSIS METHODS

This section will discuss the different data collection methods and the type of analysis that were conducted in previous studies. A summary is shown in Table 3.

Schaefer et al. (1998) used Logic Model was used for the model design to evaluate Lane Control Signing on freeways. The analysis was descriptive based on the results obtained from the model.

Rämä and Kulmala (2000) studied the effects of DMS on slippery road conditions, speed, and headway. Field measurements were used for data collection. The analysis was performed using Analysis of Variance (ANOVA).

Dutta, Fisher and Noyce Dutta et al. (2004) evaluated factors affecting the understandability of dynamic messages using a driving simulation. Results were analyzed using Comparative Analysis (Descriptive) and Analysis of Variance (ANOVA).

van Huysduynen, Terken, and Eggen (2018) used Analysis of Variance (ANOVA) to evaluate the effects of DMS on driver behavior.

Wang et al. (2009) proposed a design and evaluation methods for Incident management on freeways using LCS. Experiment was conducted on VISSIM. The analysis was conducted using Macroscopic Simulation Model and in addition, a descriptive analysis of the data.

Lai (2010) studied the effects of using different colors and different lines in DMS messages on driving behavior. Data collection was a through field measurements and survey. Descriptive analysis was performed and Chi-Square tests.

Li and Wang Z. Li and Wang (2011) evaluated driver's perception of DMS information. The analysis was made using evolutionary game of strategy selection method.

Guattari et al. (2012) studied the effectiveness of DMS information using a driving simulation. Descriptive analysis was performed, speed variation before and after the sign based on the data from simulation, and hypothesis testing (t test) was used to analyze the data.

Er-hui et al. (2013) compared the different graphical images used in a DMS. Data were collected through a survey. The analysis was performed using Hypothesis testing (t test), Multiple comparison analysis (ANOVA) in addition to Descriptive of the results.

Shaaban Shaaban (2013a) investigated the frequency for individuals to use cell-phone in Qatar. Data were collected using field surveys. The analysis was performed using SAS software to perform Pearson Chi-square tests.

Ma et al. (2014) investigated drivers' response to DMS messages. Data was collected using survey and analyzed using Multinomial Logit Model.

Vrieling, de Waard, and Brookhuis (2014) compared driving behavior on two type of road works. Data were collected in a field survey. Analysis was performed using Hypothesis testing (T Test) and Wilcoxon Signed-Ranked with LSD Correction.

Zheng, Chase, Elefteriadou, Schroeder, and Sisiopiku (2015) investigated vehicle and pedestrian interaction outside of crosswalks. Data were collected through simulation and field measurements. The developed logit model was analyzed using Correlation Analysis and Linear Regression

Son, Park, and Park (2015) evaluated the effect of different variables on the acceptance of Advanced Driver Assistance systems. Field survey was conducted for data collection. The analysis was performed using descriptive statistics, reliability analysis, two-way ANOVA for user acceptance analysis, and a mixed ANOVA for the effectiveness analysis.

M. Li et al. (2016) developed a stochastic network equilibrium model to determine optimal locations for DMS. A driving simulation was conducted for data collection. The study proposed a model and was analyzed using sensitivity analysis and proposed a paradox.

Ronchi, Nilsson, Modig, and Walter (2016) studied DMS as a way for tunnel emergency evacuation. Data were collected through surveys. The theory of affordances was conducted, and descriptive analysis was performed.

Zhizhou and Liang Wu and Liang (2017) studied the locations of DMS based on drivers' perception by using Logistic Regression method and significance analysis. Data were collected from surveys.

Zavareh, Mamdoohi and Nordfjærn Zavareh et al. (2017) investigated the driving behavior after providing warning messages on rear-end collisions in DMSs. Analysis of Variance (ANOVA) and Multiple Regression analysis was performed.

Roca, Tejero and Insa Roca, Tejero, and Insa (2018) compared drivers with reading difficulties with normal drivers on the words and pictograms used in DMS. The study used descriptive statistical analysis and Hypothesis testing (t test).

Lyu, Deng, Xie, Wu and Duan Lyu, Deng, Xie, Wu, and Duan (2018) investigated the effect of using Advance Driver Assistance System on driving behavior. The data were collected through field surveys and was analyzed using ANOVA and Greenhouse-Geisser correction which was applied for some models.

Xu et al. (2018) studied the relationship between DMS control strategies and road safety in freeway work zones. Driving simulation was used for data collection and analysis was conducted using Mixed Design Analysis of Variance (ANOVA) and descriptive analysis.

Gilandeh, Hosseinlou, and Anarkooli (2018) investigated the effect of different roadway features. Data were collected in field surveys and analyzed using Multivariate variance analysis (MANOVA).

Harms et al. (2018) investigated the effect of using traffic-irrelevant messages on driving behavior. Driving simulation was used for data collection and analysis was performed using hypothesis testing (T-test)

van Huysduynen et al. (2018) investigated the relation between the driving behavior with the participants'' self-reported driving style. The data were analyzed using hypothesis testing (T-test) and Descriptive Analysis)

Table 3, Summary of data collection and analysis methods found in literature review

Author	Year	Data Collection	Analysis Method
Schaefer et al.	1998	Driving Simulation	Descriptive analysis
Rama & Kulmala	2000	Field measure	ANOVA
Dutta, Fisher & Noyce	2004	Driving Simulation	Comparative analysis (descriptive) + ANOVA
Erke, Sagberg & Hagma	2007	Field Survey	ANOVA
Wang et al.	2009	VISSIM - Simulation	Macroscopic simulation model. Descriptive Analysis was used
Lai	2010	Field measure & Questionnaire	Descriptive analysis + Chi-square test

Author	Year	Data Collection	Analysis Method
Li & Wang	2011	The Game Model	Evolutionary Game of Strategy Selection Process
Guattari et al.	2012	Driving Simulation	Descriptive analysis + Speed variation before/after Sign + Hypothesis testing
Er-Hui, Jing, Yun-Ling & Juan.	2013	Questionnaire	hypothesis testing (t test + ANOVA) + Multiple comparison analysis (Descriptive)
Shaaban	2013	Field Survey	The Pearson Chi-square analysis using SAS
Ma, Shao, Song & Chen	2014	Questionnaire	Multinomial logit model
Vrieling, Waard & Brookhuis	2014	Field Survey	T test + Wilcoxon Signed-Rank with LSD correction
Zheng et al.	2015	Simulation and Field measure	Modeling (Correlation Analysis + linear regression)
Son, Park & Park	2015	Field Survey	Reliability analysis, descriptive statistics, two-way ANOVA and mixed ANOVA
Li, Lin, He & Jiang	2016	Driving Simulation	Equation model
Ronchi, Nilsson, Modig, & Walter	2016	Questionnaire	Theory of Affordances + Descriptive Analysis
Zhizhou & Liang	2016	Questionnaire	logistic regression method + significance analysis
Zavareh, Mamdoohi & Nordfjærn	2017	Statistics	ANOVA + Multiple regression analysis

Author	Year	Data Collection	Analysis Method
Roca, Tejero & Insa	2018	Driving Simulation	Descriptive statistical analysis + Hypothesis testing
Lyu, Deng, Xie, Wu & Duan	2018	Field Survey	ANOVA, and Greenhouse-Geisser Correction
Xu, Zhao, Chen, Bian & Li	2018	Driving Simulation	Mixed design analysis of variance ANOVA + Descriptive
Gilandeh, Hosseinlou, & Anarkooli	2018	Field Survey	Multivariate variance analysis (MANOVA)
Ilse, Dijksterhuis, Jelijs, Waard & Brookhuis	2018	Driving Simulation	Hypothesis testing
Huysduynen, Terken & Eggen	2018	Driving Simulation	Descriptive analysis and Hypothesis testing

Most of the studies as shown in Table 3 have used surveys (online and paper) for data collection. Driving experiment was also used in many studies using a simulator or field experiment.

With regards to data analysis, previous studies included descriptive analysis, hypothesis testing, analysis of variance, logit regression, linear regression, significance analysis, reliability analysis, correlation analysis, chi square test.

2.4 QUESTIONNAIRE DESIGN AND DATA SIZE

This study will use online questionnaire as a method for data collection. Zavareh et al. (2017) design the survey to start with personal questions about the participant including: age, income, driving years of experience, annual mileage and education level. After that, the participants were asked about their opinion on DMS with a 6-level satisfaction rate.

It is important to know the number of participants for the survey. After reviewing similar studies that have used paper or online surveys for data collection, the summary is shown in Table 4.

Table 4, Summary of literature review for number of participants for questionnaire

Author	Year	Data size	Remarks
Ronchi et al.	2016	62	A preliminary evaluation of 11 selected DMS systems for road tunnel emergency evacuation was performed
Ma et al.	2014	8477	This research studied driver response to information provided by DMS. The number of participants in this study was 9600 but only 8477 were considered. The survey included 13 questions
Er-Hui et al.	2013	445	This study made comparation on Variable Message Signs graphical images. The number of participants was 500 but only 445 were considered.
Tay, R., & Barros, A. D.	2010	100	This paper studied the effectiveness of Road Safety Messages on DMSs
Wu, Z., Liang, Y.	2016	500	This paper studied the DMS location selection based on drivers' perception

Based on previous studies, and the analysis shown in section 3.1.5, the required number of participants for this study will be 385.

2.5 LITERATURE REVIEW OF DRIVING EXPERIMENT

As will be explained in Chapter 3, this study will conduct a field experiment. It is important to conduct a literature review of similar studies that used field experiment for data collection. Literature review will focus on number of participants, validity of participants' self-reported data, time of the day, and variables considered.

Lyu et al. Lyu et al. (2018) evaluated the effectiveness of various advanced driver assistance systems (ADAS) and also evaluate the influence of driver characteristic on the driving behavior. This study used a field measurement by installing camera and navigation system to record the data that was obtained from 32 participants. The experiment had three parts: in the pre-experiment the driver was asked to fill a questionnaire about their safe driving, after that the experiment happened. Finally, after the experiment is done, the driver was asked to fill a questionnaire about the ADAS. The results show that ADAS significantly affects braking behavior, longitudinal deceleration and headway time. This study is not directly related to the topic of this research. However, the methodology of this study is applicable in this research also and was used for reference. Variables used for the field study included speed, gas pedal position, brake pedal pressure, longitudinal plus acceleration, longitudinal minus acceleration, time headway, lateral acceleration, number of lane changes, lane deviation, number of braking occurrences, relative speed when braking, brake energy and the maximum deceleration. The field study was conducted during the day from 8:00 to 17:30.

Vrieling et al. (2014) aimed to evaluate the improvements of road design with a new adopted format in Netherlands. The method used in this study was a field measurement for both types of roads (current and new) with 25 participants. Video cameras and GPS equipment was installed to record the data of the experiment. A questionnaire was handed to the participants after each part of the experiment and asked them to mark their rating scale mental effort from 0 to 150. Results show that drivers comply more with the new road works more than the current. Mental effort was compared between the two roads and found that it was more invested was higher in the new road works even though speed was also higher. This study is not directly related to the topic of this research. However, the methodology of this study is applicable in this research also and was used for reference. Variables used for this study include Speed, lateral position, Position of the Hands on the Steering Wheel, Self-reported Mental Effort, Opinion about Speed Limit and Lane Width, and Road Works, Intensity. Field study was done daylight and off-peak hours.

Son et al. (2015) investigated the effect of socio-economical characteristics of drivers and the roadway environment on the acceptance of the Advanced Driver Assistance Systems (ADAS). This method used in this study was a driving experiment with 52 participants where participants drove on different types of roads, and a questionnaire was handed to the participants after completing the experiment. The questionnaire first defined the driver characteristics and then measured the driver perceived stress while driving on the roads, and finally measured the user acceptance of the ADAS in a 7-point rating scale. Variables used in this study included Average lane departure warning counts (LDWC) and the standard deviation of lane position, number of lane excursion without turn signaling, lateral position. The field survey was done during off-peak hours.

Gilandeh et al. (2018) investigated the effects of three roadway features on bus driver behavior using a driving simulator. The roadway features are: shoulder width, presence of guardrail, and the roadway geometry. The experiment took time on bus day/night lighting conditions. The number of participants in this study was 40 professional bus drivers and the driving route consisted of 30 different segments. it was found that the deployment of guardrail on narrow shoulder segments have a noticeable effect on bus driver behavior. However, results also revealed that the presence of guardrail has a negative effect on driving speed and encourage drivers to maintain the lateral position in the center of the lane. With regards to the lighting conditions, results show that drivers tend to drive at higher speeds in daylight and low speeds at night times. Lateral positioning, however, was not affected by lighting condition. Variables included in this study were the average driving speed, and average distance from centerline which was obtained for different scenarios. The field study was done in daylight and night times.

2.5.1 NUMBER OF PARTICIPANTS IN DRIVING EXPERIMENT

It is important to know the number of participants for the survey. After reviewing similar studies that have used paper or online surveys for data collection, the summary is shown in Table 5.

Table 5, summary of literature review for number of participants in field study

Author	Year	Data size	Remarks
Lai	2010	30	This paper studied the effects of using different colors and message lines of DMS on driver behavior. The study used 30 participants, and a total of 84 random DMS messages
Guattari et al.	2012	20	This paper used a driving simulation to study the effect of information provided by DMS on driver behavior. In this study 20 number of drivers participated in the simulation
Dutta et al.	2004	48	This paper used a driving simulator to evaluate and optimize different factors that can affect the drivers' understanding of DMS messages. A total of 48 drivers participated in the simulation
Xu et al.	2018	32	This paper studied the relationship between DMS control strategies and driver safety in freeway work zones. A total of 32 drivers participated in this study.
Harms et al.	2018	32	This paper studied the use of traffic-irrelevant messages in DMS on traffic management. A total of 32 drivers participated in this study

Based on literature review, the number of participants ranged from 20 to 48 for similar studies. Average number of participants was 32.

2.5.2 VALIDITY OF PARTICIPANTS SELF-REPORTED DATA

The experiment will have post-experiment interview with questions about the driving routes. Participants will provide their opinions and self-reported evaluation. van Huysduynen et al. (2018) investigated the relation between self-reported driving style and driving behavior by collecting data from 88 participants who took a driving simulation and provided their self-reported evaluation. The results revealed a modest correlation between self-reported driving behavior and the driving behavior data obtained from the simulation.

2.5.3 TIME OF THE EXPERIMENT

Driving experiment can give different results based on time of the day. It is important to review similar studies in order to decide on the time of the day for the experiment. Table 6 shows a summary of different studies that had a field study or driving experiment and the time of the day that was considered.

Table 6, Summary of literature review for field study time of the day

Author	Year	Time of the day	Remarks
Vrieling, J., Waard,D. & Brookhuis, K.	2014	Day time and off-peak hours	This paper studied driving behavior on two different type of roads works, the standard Dutch road works design and an adapted format. The study was made in daytime and off-peak hours
Zheng et al.	2015	Night time	This paper modeled padestrian interactions outside of padestrian crossings. The study was done on weekdays starting at 4:30 pm
Son, J., Park, M. & Park, B	2015	Off-peak hours	This paper stuided the effect of different factors on the reciption of Advanced Driver Assistance Systems. The experiment was made on off-peak hours
Xu et al.	2018	Day time	This research studied the relationship between different DMS on control strategies and road safety in freeway workzones. The simulation used daytime and different Traffic conditions
Lyu et al.	2018	Day time	This paper exlpored the effect on driving performance and breaking behavior when using an advanced driver assistance system. The study was done in daytime from 8:00 am to 17:30 pm.
Gilandeha, S., Hosseinloua, M. & Anarkooli, A.	2018	Day time and night time	This study used a driving sumulator to examine the driver behavior of bus drivers to be used as a function of the road featrues. The study simulated daytime and nighttime in the experiment.

Based on literature review, there is a variety of times that was chosen for the field experiment. However, off-peak hours will be used in this study.

2.5.4 VARIABLES

Last but not least, it is important to review what variables was measured in previous studies driving experiment. It is noted that some studies used driving simulator, while others were conducted on field. A summary of previously used variables is shown in Table 7.

It was noticed that speed is the most important variable as it was collected in most reviewed previous studies, followed by lateral position, and drivers' opinion. Other variables including traffic weather conditions, number of lane changes with and without signaling, number of braking occurrences, recall and recognition, compliance behavior, and self-reported mental effort.

Table 7, Summary of literature review for variables used in field survey

Author	Speed / Average speed	Traffic Weather Conditions	Lateral position	No. of lane changes	No. of braking occurrences	Self-reported Mental Effort	Drivers' opinion/comments	Questionnaire to validate results	No. of lane changes without signaling	Compliance behavior	Recall and recognition	Remarks
Zheng et al. (2015)	*	*								*		This paper modeled pedestrian interactions outside of pedestrian crossings.
Lyu et al. (2018)	*		*	*	*							This paper explored the effect on driving performance and breaking behavior when using an advanced driver assistance system
Vrieling et al. (2014)	*					*	*					This paper studied driving behavior on two different type of roads works, the standard Dutch road works design and an adapted format
Xu et al. (2018)	*		*					*				This research studied the relationship between different DMS on control strategies and road safety in freeway work zones.
Son, J., Park, M. & Park, B (2015)			*	*					*			This paper studied the effect of different factors on the reception of Advanced Driver Assistance Systems.
Gilandeha, S., Hosseinloua, M. & Anarkooli, A. (2018)	*		*									This study used a driving simulator to examine the driver behavior of bus drivers to be used as a function of the road features
Harms et al. (2018)	*						*				*	This paper studied the effect of different traffic-irrelevant messages on the performance of DMS

2.6 CONCLUSION

Considering the aforementioned studies, despite having many studies focusing on the impact of DMS and LCS on driving behavior, traffic management, and road safety, very few studies were found that reviewed this topic in the region and none were in the state of Qatar. However, there are similar studies in the region for different elements in transportation and traffic safety.

With regards to DMS impact on driving behavior, it is found that DMS will have positive impact depending on the following elements: location of the DMS, type of message contents, display of the message including colors, number of lines, and phasing. Also, it is important that the drivers understand and trust the message.

With regards to LCS, based on previous studies, it is found that LCS will be highly beneficial when the compliance rate is high. However, when the compliance is low, the LCS is useless. Hence, it was recommended in previous studies that LCS be connected to other systems and enforced to achieve its goals. Moreover, LCS will not function efficiently in heavy traffic conditions.

Based on the previous studies, surveys are efficient method of data collection that was found in many studies. It is important to have a large sample of participants in order to have a reliable data that can be considered for analysis.

Other data collection method that was found in previous studies was in conducting a driving experiment though a simulator or field driving. The number of participants in a field experiment is not expected to be as large as an online survey for i.e., and hence, previous studies used number of participants ranging from 20 to 48 with 32 being a common size in many studies.

The validity of participants' self-reported data was reviewed in previous studies and found a modest correlation between self-reported data and the actual data collected from a simulator.

With regards to the driving experiment, the time of the day for the experiment to be conducted was reviewed based on previous studies which was found to be different from each other. Hence, the driving experiment in this study will be fixed to off-peak night time. Variables that was collected in in past studies included: speed, lateral position, self-rated mental effort, signs rating, lane changing, recall and recognition, signs following, harsh breaking, using of hands on steering wheel.

CHAPTER 3: THE PROPOSED METHODOLOGY

The methodology that was used for evaluating road user's perception of dynamic signs and their effect on driver's behavior was done in two methods; first, an online questionnaire was shared to the public about their opinions on DMS signs in Doha. In addition to that, a driving experiment was done to evaluate and compare driver behavior when observing intelligent electronic signs such as DMS and LCS, compared with the same driver driving on a normal road where no electronic signs are present. Hence, a route was defined that contain sections with and without electronic signs. The driver will then drive the complete route and after they complete the experiment, a short interview was made with the drivers and they were asked questions about their trip. Data was collected also from the trip and was studied and analyzed.

3.1 DRIVER'S OPINION QUESTIONNAIRE

3.1.1 RESEARCH DESIGN

The study of drivers' perception of ITS traffic signs was not considerably explored in the region. Based on previous studies in other regions, there are some expectations on the results, but actual results may vary tremendously. Therefore, the research is considered exploratory.

3.1.2 DATA SOURCES

In the first part of this study, data was obtained from an online survey. The survey will provide large amount of data which will be statistically analyzed. The results of the online survey will determine drivers' perception of DMS in Qatar.

3.1.3 DATA COLLECTION TECHNIQUES

The required number of surveys is determined based on the literature review, and statistical analysis knowledge. The survey questions were determined based on the objective of the study. The survey was circulated online to get as much number of participants as required. It should not take more than 10 minutes to complete the online survey.

3.1.4 QUESTIONNAIRE DESIGN

The questions that was used in the survey was developed based on the objective of the study and based on the literature review. Since the study is designed in Qatar which is an Arabic-speaking country, but with a high percentage of expats that makes English another main language in the country, survey was made in both Arabic and English languages. For ease of data distributing the survey, and collecting the data, the survey was made online using SurveyMonkey website. The objective is to study peoples' perception of DMS messages. DMS are used to notify the drivers of road closures, weather/road conditions, special events, travel time, etc. Hence, the questions were related to each type of message. The survey started with an introduction about the objective of the study and will explain to the participant what a DMS is. This helped the participants understand the upcoming questions and will give them an idea how their participation will help this study. Figure 3 shows a breakdown of the questionnaire design.

The survey is estimated to take 10-15 minutes with 34 Questions including: nine personal information, five general questions, four road conditions, four road constructions, four weather conditions, four general advisory messages, and four celebration/general messages. A layout of the questionnaire design is shown in Figure 3.

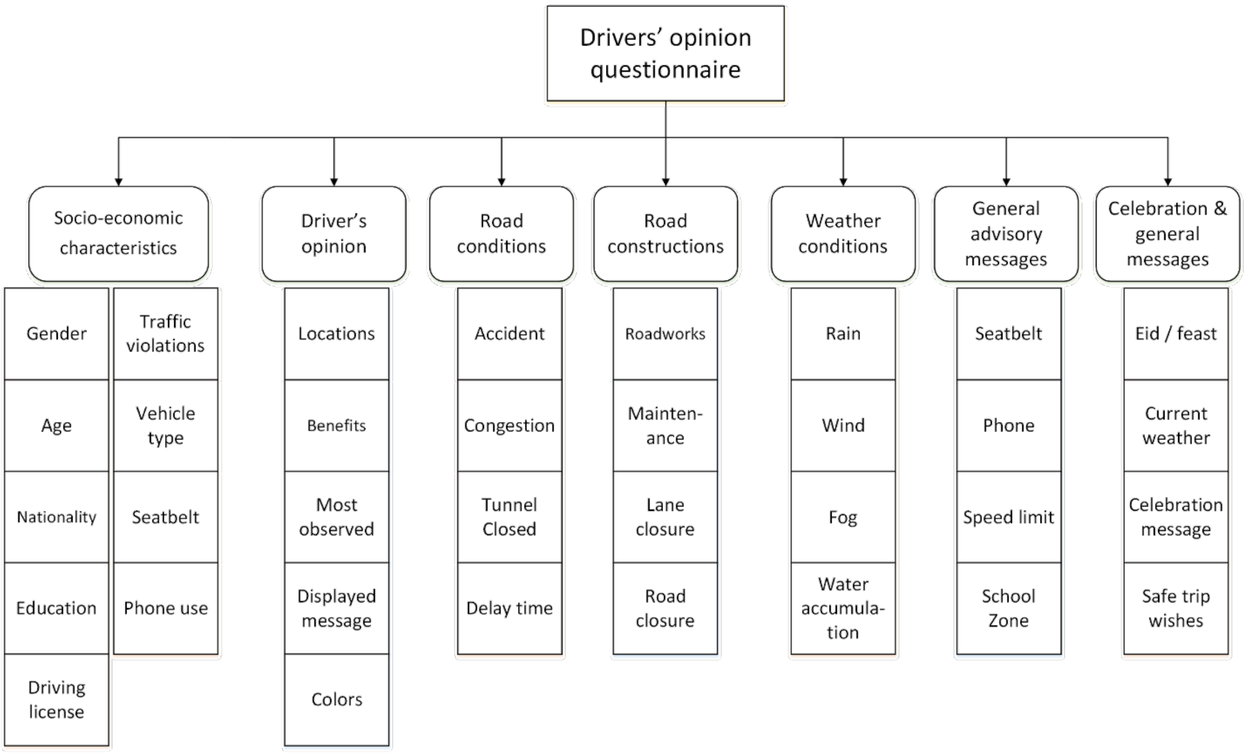

Figure 3, Drivers' opinion questionnaire on types of DMS messages

3.1.4.1 Socio-economic characteristic

The first set of questions was regarding personal information of the participants. Gender, age, nationality, and education level help to determine the kind of participants undertaking this survey. The participants must be above the age of 18 and have a valid Qatari driving license. The survey asked how long the participant had a license and the number of traffic violations received in the past three years. This helps in determining the driving behavior and the experience of the participant with driving. Moreover, additional questions regarding type of vehicle, seat-belt use, and phone use while driving was collected and to be linked to drivers' driving behavior. The type of vehicle may affect the driver's decision when he or she is confronted with a weather condition message. Seat-belt use can be linked to the driver's decision when receiving an advisory message about using the seat-belt. Similarly, an advisory message about the use of mobile phones while driving may affect the drivers' decision if they normally use it while driving. Recent studies in Qatar showed that there a high percentage of drivers use phone while driving which is considered high compared to other countries (Shaaban, 2013b; Shaaban & Abdelwarith, 2018; Shaaban, Gaweesh, & Ahmed, 2018).

3.1.4.2 General Questions

The second part of the survey was regarding the experience the participant had with a DMS while driving on the road. The first questions were based on participants ability to recall DMS usage and locations in Qatar, not specifically but generally. There is currently a large number of DMSs inside the city of Doha and more on the way as mentioned earlier, and based on this question, it will determine where people have noticed them most.

Participant also ranked the information provided in a DMS message based on how often they were observed in the country. Moreover, the survey asked the participant about his opinion of the information provided in the DMS, if they are useful or not.

Lastly, some general questions will ask about the color of the text, and the use of pictograms. As DMS messages in Qatar tend to use more than one color, it will help conclude which color is easier to understand while reading. Also, pictograms can be useful to give the message without actually reading the text, but they can also be confusing to some. The survey analysis will conclude the easiest way of presenting a message for the drivers.

3.1.4.3 Road Conditions

The third part of the questionnaire was more specific to certain type of messages. Road Conditions refer to the current status of the roads. It can refer to a road closure, a traffic congestion, an incident ahead or a travel time information as shown in Figure 4.

Road or tunnel closure is an important message to alert the drivers that they cannot access or continue on the same road, and they have to change their route. If the drivers fail to observe and apply the message, there is a huge risk of accident or congestion. It is important to see what the driver will understand from a certain message and what action they will take.

Figure 4, Example of road conditions messages

Another type of message can refer to a traffic congestion or accident ahead, which will allow the drivers to take a smart decision to continue on the same route or change it. The road conditions message can come in a form of estimated time of arrival that will give the drivers information about their route duration in order to plan ahead. It is possible that drivers may ignore these messages or think they are unnecessary as their destination is not related to the messages. This study will analyze the drivers' view on travel time messages.

Lastly, this study will also analyze drivers' trust of the provided DMS information. Drivers care more likely to follow the instructions if they trust the message but can also take decision not to follow it. Based on the provided options in the questionnaires' answers, it will determine whether drivers trust DMS information or not, and whether they find the messages need to give more information to take a decision.

3.1.4.4 Road Constructions

The infrastructures in Doha is being massively upgraded to prepare the country for the upcoming FIFA World Cup event in 2022. Due to that, the roads of Doha are changing every day with construction works happening on almost every main road. DMSs can provide the drivers with information about construction works ahead that will warn the drivers and prepare them for the approaching road condition. An example of construction messages is shown in Figure 5. The messages can advise the drivers to slow down, or generally stating that the road is undergoing some maintenance works. Some drivers tend to ignore these messages or no longer trust the given information which was analyzed in this study. Also, the message can warn the drivers that the road ahead is completely closed or some of its lanes. These messages should be followed by the drivers, otherwise may result in a major accident.

Figure 5, Example of road construction messages

3.1.4.5 Weather Conditions

Weather condition messages is used to advise the drivers of a certain danger ahead. Failure to observe and understand the message may put the driver in a danger of accident. Qatar's climate is normally dry, clear and save to travel. However, there are number of days the country experiences a sand/dust storm or fog that limits the visibility and the drivers may not be expecting this condition. The survey will study the drivers' reaction upon observing a message related to rains, heavy winds, fog, and water accumulation on the road. The participants were given options whether to slow down, follow other vehicles' speed, change route, do nothing or if they require more information to take the decision. The questions may have some correlation with the personal information of the participants such as vehicle type. As low-ride or sport vehicle tend to be more damaged due to water accumulation of heavy wind/dust. The analysis will determine how drivers will react from certain messages about the weather conditions.

Figure 6, Example of weather condition messages

3.1.4.6 General Advisory Messages

DMSs can be used to advise on current conditions of the roads, as portraited above, or can give general advisory messages that is not related to the current event. These messages are mostly shown on a static, but a DMS may be more appealing to the road users. As shown in Figure 7, These messages can advise the drivers to slow down in school zones or urban areas, reminding to follow the speed limit, or advise the drivers to wear a seat-belt or not use the phone the phone while driving. The analysis will study if the participants find these messages useful, or not. Results may show that the participants find these messages distracting. Finally, the analysis will study if there is any correlation between the participants answers and their personal information such as, traffic violations, wearing seat-belt, or using the phone while driving.

Figure 7, Example of general advisory messages

3.1.4.7 Celebration and general messages

Qatar has been known to the world to host international sports events. The country also has a number of national holidays and feasts. It is noticed that DMS are used to celebrate these events or displaying general messages such as "have a safe trip" or the date/time of the day. Example of these messages is shown in Figure 8. It is important to study what people think of these messages and are there any risks of displaying such messages. Using large pictures to celebrate such events may disturb the drivers or result in drivers ignoring the DMS after observing it multiple times. The survey will determine drivers' judgement of special events messages.

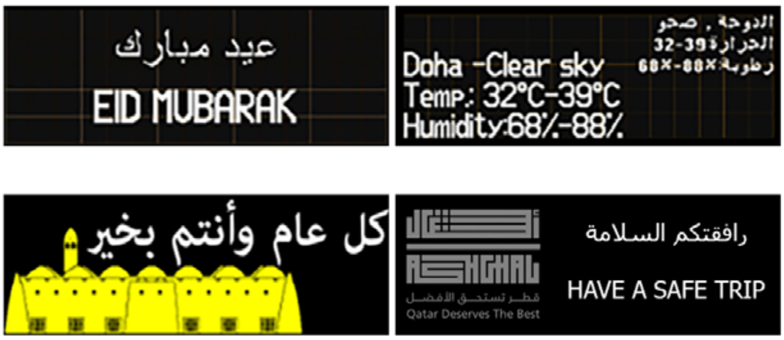

Figure 8, Example of celebration and general messages

3.1.5 SAMPLE SIZE

The questionnaire is developed to obtain data in order to analyze the drivers' perception of DMS. The data size that was used for this study was determined by using the following sample size formula:

$$ss = \frac{Z^2 * p * (1 - p)}{c^2}$$

Where:

Z = Z value

p = percentage selecting a choice, expressed as decimal

c = confidence interval, expressed as decimal

Table 8, Parameters used for sample size calculation

Parameter	value
Z	1.96 (for 95% confidence level)
p	0.5
c	0.05

Based on the parameters used in Table 8, this results in a required sample size of 385.

3.1.6 PILOT STUDY

Pilot studies are small-scale, preliminary studies that aim to investigate the components of a main study. They help in determining whether the main study can and was able to achieve its objectives, and they highlight any problems in the main study.

A pilot study was conducted for road users' perception of DMSs study. There were ten individuals that participated in the pilot study. The participants came from different backgrounds. Five of them are from a traffic engineering background and working in the public works authority in designs and construction of ITS in Qatar. The other five participants have other backgrounds, but all are road users driving on the roads of Qatar. Feedback on the survey questions, durations and any other observation was considered in the final version

Below are the comments received from the participants on the pilot study:

1- Generally, participants found the survey easy to understand and not very long to complete.
2- With regards to general advisory messages, some participant said their answer weren't shown in the multiple choices. Therefore, another option was added "Other – please specify:"
3- On questions regarding speed limit under general advisory messages, participants found that more than one answer are applicable to them and suggested rephrasing the choices which were updated in the final version.
4- Participants highlighted strongly to consider adding an option that the celebration/general messages can distract drivers which was added in the multiple choices.
5- Lastly, some the participants suggested to add a choice "I like seeing such messages on the roads" on the last questions related to celebration/general messages.

Based on the findings of the pilot study, participants did not find any major issues in the content of the survey, but gave some feedback that, in their opinion, can improve the survey quality. These comments were taken into consideration in the final published survey.

3.1.7 PARTICIPANTS INFORMATION

The questionnaire was distributed online. A total of 402 individuals participated in the survey. Table 9 shows participants characteristic information.

Table 9, Participants Information

Gender	Male	211
	Female	191
Age	18-25	35
	26-35	175
	36-50	139
	51-65	53
	More than 50	0
Nationality	Asia	51
	Europe/North America	281
	Non-Qatari Arab	39
	Qatari	29
	Other	2
Level of education	Not Graduated from High school	6
	High school	50
	Diploma	39
	Bachelor	229
	Higher Education	78

3.2 IMPACT OF DMS AND LCS ON DRIVER BEHAVIOR

The second objective of this study is to review and compare driver behavior when implementing dynamic signs (DMS and LCS) using a real -life driving experiment. This study will compare driver behavior between three type of roads; arterial roads, freeway with, and without ITS signs. The experiment was conducted in Doha on a specific route that is designed to have all three type of roads that needs to be studied.

3.2.1 DATA SOURCES AND COLLECTION TECHNIQUES

The data was collected from interview questions and video camera recordings of the experiment. The camera that was used in the experiment is equipped with GPS. Other equipment will be used to collect speed.

The required number of participants was determined based on the literature review, and statistical analysis knowledge. The variables that was measured was determined based on the objective of the study. The drivers will drive the same route which contains sections with the electronic signs and sections with only static signs. The trip was recorded using two cameras equipped with GPS, one aimed front, and the other captured the drivers' hand. The camera will record the time, position, and speed. In addition, an interview with the driver was made and about his observation and opinion on the routes.

3.2.2 THE EXPERIMENT DESIGN

In order to evaluate the drivers' behavior when receiving a message from electronic signs, an experiment will be made that involves a driver using a specific route that include a number of DMS and LCS signs. The drivers were not informed of the study objective or what will they be asked about after the driving is finished. This to encourage participants to drive normally on the route without any instructions. Upon finishing the route, the driver will be asked questions based on his driving experience from this experiment. Figure 9 shows the breakdown of the driving experiment variables and collection methods. Lastly, an observer will record some of the variables shown in Figure 9, and will conduct the post-experiment interview.

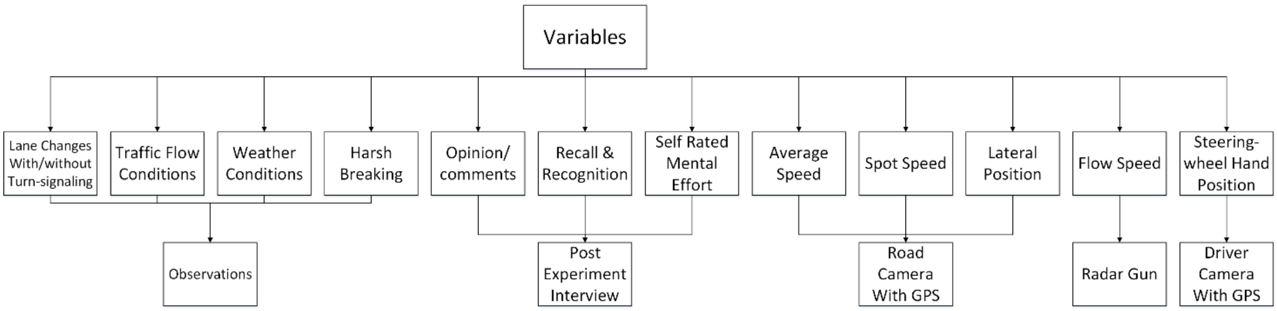

Figure 9, Driving experiment variables

3.2.3 EXPERIMENT ROUTE

The state of Qatar is currently installing several DMSs and LCSs on the roads which can be found in multiple corridors. A survey was made to determine the locations of dynamic signs inside Doha and the locations is shown in Figure 10.

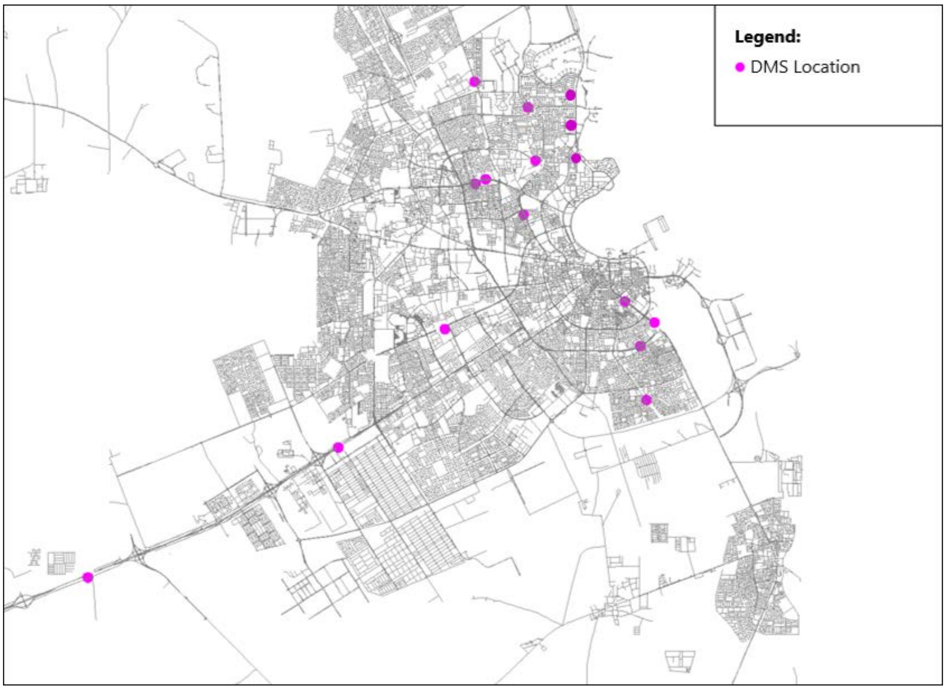

Figure 10, Locations of existing DMS in Doha

After reviewing several sites, a corridor was selected that include arterial road, freeway with and without DMS and LCS installed. The corridor is shown Figure 11. The advantage of the chosen route is that it is continues (one corridor) and does not require the drivers to move from one location to the other to start another section. The route also has a convenient parking places near the start of the route and right after the end which was used for to meet with participants and have the post-experiment interview.

The first section of the corridor (route 1) starts from a traffic signal intersection on the arterial road and ends once the driver enters the interchange. Route 1 is 3.0 Km long, four lanes in each direction, and has three traffic signal intersections. Route 1 has a posted speed of 80 kph.

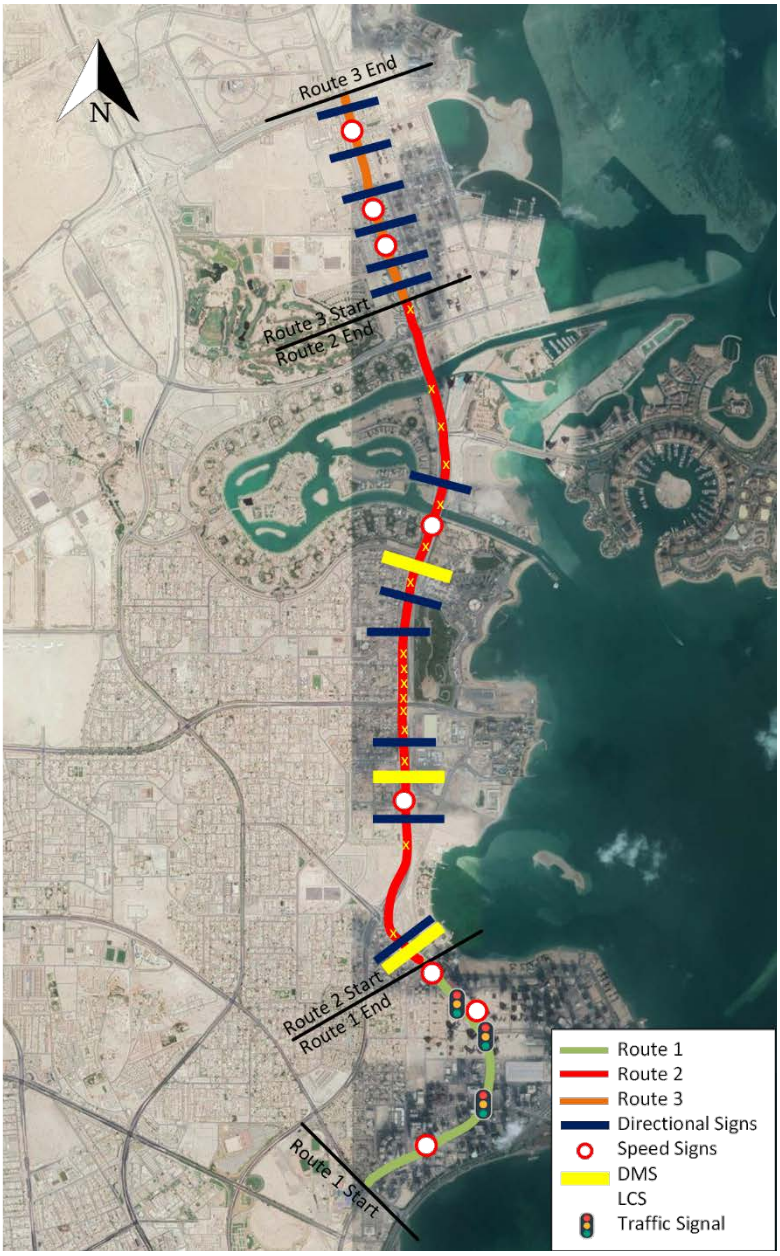

Figure 11. Driving experiment route

Route 2 starts from Lusail 5/6 interchange and ends after the pearl interchange. It is 5.3 Km long, 4 lanes wide, and has 2 tunnels with 350m and 600 m of covered length in each direction. Route 2 also includes 3 DMSs and 17 sets of LCS. The posted speed for route 2 is 80 Kph. A high-level layout of route 2 DMS and LCS implementation is shown in Figure 12.

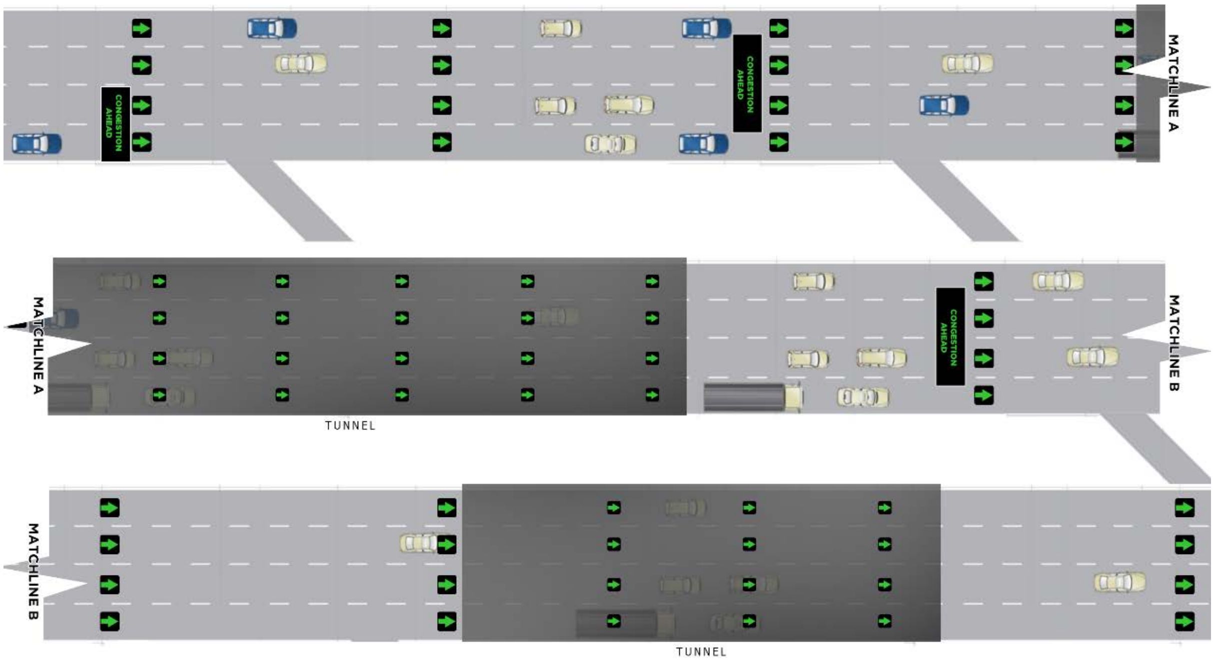

Figure 12, Route 2 high-level layout

Route 3 starts right after route 2 ends. It is a freeway, 3.2 Km long with 4 lanes in each direction and a posted speed of 80 kph. Route 3 does not include any DMS or LCS. Table 10 shows a summary of the three routes.

Table 10, *Summary of possible routes*

Parameter	Route 1	Route 2	Route 3
Distance	3.0 Km	5.3 Km	3.2 Km
Posted speed	80 Kph	80 Kph	80 Kph
No of lanes	4	4	4
No of DMS	0	3	0
No of LCS locations	0	17	0
No of speed limit signs	3	2	3
No of directional signs	0	6	7
No of traffic signals	3	0	0
No of interchanges	0	3	3

3.2.4 VARIABLES

The variables obtained from the driving experiment will be based on the literature review. Below is a breakdown of each variable, and the data will be obtained.

3.2.4.1 Speed

Speed is the most important factor to consider when comparing roads. Previous researches have considered this variable in their study. Lyu et al. Lyu et al. (2018) recorded speed in their study about ADAS systems. Vrieling et al. (2014) also calculated average speed to compare two types of road works. Xu et al. (2018) used speed as a variable in the research on the relationship between DMSs.

In this study, Speed was used as a variable. It was recorded in three methods. First, the observer used the remote radar equipment to measure a sample of surrounding vehicles speed. Thirty-two measurements were recorded for each method to achieve an acceptable sample size. The second method was using the GPS Camera. It is noted that since route 1 contains a number of traffic signals which will require braking to stationary speed and acceleration from zero, a distance of 100 m before and after intersection was not recorded in both methods. The third method is from the average speed of the vehicles in which the distance of the route is divided by the entry/exit time for each participant. It is noted that route 1 will include stopping at intersection which will affect the average speed.

3.2.4.2 Harsh Braking

Harsh braking was another variable to consider. Many studies used deceleration and harsh braking as a variable. Lyu et al. Lyu et al. (2018) recorded change in speed which is acceleration/deceleration. Vrieling et al. (2014) and Xu et al. Xu et al. (2018) used braking as a variable in their studies. In this study, the number of harsh braking incident made by the participant on the test will be measured and recorded by observer.

3.2.4.3 Traffic Flow Condition

Refers to the condition of the traffic flow at the time of each experiment trial. Measured by both observer and participant judgements. Zheng et al. used Traffic flow condition as a variable in their study about pedestrian interactions outside of the crosswalk zone. The traffic flow conditions will be recorded as; low, medium, or high.

3.2.4.4 Weather Conditions

Refers to the condition of the weather at the time of each experiment trial. Measured by observer's judgement. Weather conditions was used as a variable by Zheng et al. In this experiment, weather conditions will be categorized in three classes; normal, rainy, dusty.

3.2.4.5 Number of Lane Changes

The number of lane changes made by the participant on the test segments. Lane change was used as a variable by Lyu et al. Lyu et al. (2018). In this study, number of lane changes will be measured by a combination of lane changes with and without turn signaling.

3.2.4.6 Number of lane changes with turn signaling

The number of lane changes made by the participant on the test segments while using turn signaling indicators. Measured by observer's observation.

3.2.4.7 Number of lane changes without turn signaling

The number of lane changes made by the participant on the test segments without using turn signaling. It was considered as a variable in Son et al. (2015) study about the effects of different variables on and effectiveness of ADAS system. In this study, Lane changes without turn signaling will be measured by observer's observation on each segment.

3.2.4.8 Lateral Position

The position of the vehicle with respect to the lane. It was used in Vrieling et al. (2014) study and was defined as the distance from the edge of the car to the lane edge due to different lane width. In this experiment, the corridor has a fixed lane width of 3.65 m. And for the objective of this study, lateral position will be defined by 3 categories: Within Lane, Edge of the lane, Crossing the lane marking. It is expected that the driver will mostly maintain the vehicle within the lane. Hence, it is measured based on the vehicle distance from the edge of the lane or crossing the lane with respect to the corresponding route segment. Video recordings were used to measure the lateral position.

3.2.4.9 Position of the hands on the steering wheel

The position of the drivers' hand on the steering wheel. Vrieling et al. (2014) categorized the position of the hands in 3 categories: High, medium, low control; where high control means that both hands were used in a high control position (which is around the 3 o'clock and 9 o'clock position of the steering wheel). Medium control is using both hands not in 3 and 9 o'clock, or 5 and 7 o'clock positions. Low control is using one hand in any position or both hands in 5 o'clock or 7 o'clock positions. In this study, the position of the hands will be measured by the duration of each position based on the observer judgment

3.2.4.10 Self-reported mental effort

Participant mental effort invested on each segment. Vrieling et al. (2014) also used in their study the self-reported mental effort in a questionnaire. In this study, Participants will be asked in the post-experiment questionnaire to record what they believe was the mental effort to drive on each segment measured from 1-5, with 1 being lowest effort (best), and 5 being the most demanding.

3.2.4.11 Recall and Recognition

Recall and Recognition was used in previous studies about DMS traffic-irrelevant messages (Harms et al., 2018). In this study, drivers were asked in the questionnaire to recall the number of signs for speed limit signs, directional signs, DMSs, and LCSs for each segment, which was later compared with the actual number of signs.

3.2.4.12 Compliance behavior

Compliance behavior was used in previous studies about drivers' compliance with the use of traffic-irrelevant messages in DMS (Harms et al., 2018). In this study, compliance was measured by drivers' compliance to speed, lane changing, lateral position which is obtained from previous variables.

3.2.4.13 Opinion/comments

Participants' opinion of the quality of each segment, and comments about any other issues. This was used in many studies such as Harms et al. (2018) and Vrieling et al. (2014). At the end of the experiment, participants were asked in the post-experiment questionnaire about their opinion and provide comments if they want.

3.2.5 POST-TRIP QUESTIONNAIRE

After each participant completed the drive, they were asked questions about their trip. There were three type of questions that were asked to the participants. First, personal questions about the driver characteristics. Second part is about route specific questions regarding what they saw, how they reacted, and what is the exposed mental effort for driving on each route in their opinion. Lastly, some general questions regarding their opinion on the LCS.

3.2.6 SAMPLE SIZE

The number of participants needs to be defined based on the literature review. Most of the studies found in the literature review used driving simulation for their studies. Since this study is using a real-life driving experiment, which is close to a driving simulation when it comes to participants' effort, the number of participants will be used similar to the driving simulation participants used in other studies.

Guattari et al. (2012) used 20 participants in their study about the effectiveness of DMSs information on the drivers. Other studies have used 48 participants for a driving simulation as Dutta et al. (2004) used in their study about evaluating and optimizing factors affecting understandability of DMSs. Lyu et al. Lyu et al. (2018) used 32 participants in their study about the effect of advanced driver assistance system on driving performance and braking behavior.

Similarly, Xu et al. (2018) used 32 participants in their study about the relationship between DMS control strategies and driving safety in freeway work zones. Other studies used a smaller number of participants i.e., Vrieling et al. used 25 participants in the study comparing two Types of Road Works in the Netherlands.

Based on the above, the number of participants used for this study is 32.

3.2.7 TESTING VEHICLE AND EQUIPMENT

Based on the literature review, most of the studies were made on driving simulator computer software. Hence the vehicle was fixed. However, Lyu et al. Lyu et al. (2018) made the test in drivers' own vehicles. In this experiment, Test Vehicle will be fixed regular car sedan type equipped with a camera and a GPS tracker. Garmin Dashcam 20 will be used for the experiment since it has both functions of recording and GPS tracking. As shown in Figure 13, two cameras will be used; one facing the front of the car (Figure 14), and the other facing the driver (Figure 15). In order to capture the speed of other vehicles, a remote radar gun was used.

Figure 13, Placement of road and driver cameras

Figure 14, A view from the road camera

Figure 15, A view from driver's camera

3.2.8 PILOT STUDY

Pilot is also made for the driving experiment. Two participants have taken all parts of the test including the post-experiment questionnaire. After that, the participants were asked about their opinion of the experiment and comments or observation they have. The participants stated the following observations:

1- Measuring other vehicles speed affected visibility of the right-side mirror. Upon practice, this issue was resolved by aiming the radar gun far from the line of sight with the mirror.

2- Limits of each route were not clearly understood. A map was printed and was shown to every participant before and after the experiment.

3- Directional signs were ignored due to the fact that they have a static route.

The above comments were considered in the final experiment design.

3.2.9 PARTICIPANTS INFORMATION

Summary of the participants' demographics is shown in Table 11. It is noted that the demographics chosen for this experiment represents the population of Qatar which has 11.6% of Qataris and 88.4% of expats. The country also has a majority of males with 74.9% of the total population compared to 25.1% of females.

Table 11, *Participants' Information*

Gender	Male	71.9%
	Female	28.1%
Age	18-25	21.9%
	26-35	56.3%
	36-50	15.6%
	More than 50	6.3%
Nationality	Asia	3.1%
	Europe/North America	6.3%
	Non-Qatari Arab	75.0%
	Qatari	15.6%

CHAPTER 4: ANALYSIS OF DRIVERS’ PERCEPTION OF DMS

The personal socioeconomic characteristics of the surveyed sample are summarized in Table 12. Of the 402 surveyed participants, 52.5% were male and 47.5% were females. Most of the participants were between the ages of 26 and 35, which account for 43.5%. Also, the majority of the participants are non-Qatari Arabs with 69.9% of the total. With regards to education, most of the participants holds a university degree. The distribution of participants’ valid driving license within the sample was relative. The majority of the daily driving vehicle was SUV-type vehicle, which account for 51.7%, and the distribution of. The driver’s number of traffic violations in last 3 years was divided into none, once, 1 to 3, 3-5, more than 5 times, and the proportions were 42.8%, 22.6%, 18.2%, 10.7%, 5.7% respectively. With regards to seatbelt use, 72.6% of drivers always used seatbelt and only 3.0% said they never use seatbelt while driving. The distribution of phone use while driving was almost spread evenly between most of the time, sometimes, when necessary, never with 18.9%, 30.1%, 34.1%, 16.9% respectively.

4.1 SOCIO-ECONIMICAL CHARACTERISTIC OF THE SAMPLE

Table 12, Sample characteristics

Characteristics	Answer Choices	Responses
Age	18-25	8.7%
	26-35	43.5%
	36-50	34.6%
	51-65	13.2%
Nationality	Qatari	12.7%
	Non-Qatari Arab	69.9%
	Europe / North America	9.7%
	Asia	7.2%
	Other	0.5%
Education	Not Graduated from High school	1.5%
	High school degree	12.4%
	Diploma	9.7%
	University Bachelor degree	57.0%
	Higher Education	19.4%
License Validity	less than a year	6.2%
	1-5	12.2%
	5-10	25.1%
	More than 10 years	56.5%
Traffic violations in last 3 years	None	42.8%
	1	22.6%
	2-3	18.2%
	3-5	10.7%
	More than 5	5.7%
Vehicle type	Sedan	38.6%
	SUV	51.7%
	Pickup Truck	4.5%
	Van	1.2%
	Motorcycle	0.3%
	Other	3.7%
Seatbelt use	Always	72.6%
	Most of the time	16.9%
	Sometimes	7.5%
	Never	3.0%
Phone use while driving	Most of the time	18.9%
	Sometimes	30.1%
	When necessary	34.1%
	Never	16.9%

4.2 DRIVERS’ OPINION ON EXISTING DMS

Participants were asked where they have seen a DMS before in Doha. Responses are shown in Table 13.

Table 13, Participants opinion on locations of DMS signs

Answer Choices	Responses
Never seen it before	2.0%
limited locations	38.3%
Several locations	38.0%
Most main roads	21.6%

Participants were asked if they think DMS provide useful information. Table 14 shows their responses.

Table 14, Participants’ opinion of usefulness DMS information

Answer Choices	Responses
Strongly agree	42.7%
Agree	37.8%
Neither agree nor disagree	12.7%
Disagree	6.3%
Strongly disagree	0.6%

Based on the responses provided in Table 14, it is found that the majority strongly agree that DMS provides valuable information with 42.7% of total participants. This is in line with Ma et al. (2014) study that concluded that most people believe DMS messages are important.

With regards to the information provided by the DMS, participants were asked to rate the messages based on their observations in Doha. Table 15 shows participants’ responses: where lower value means message was observed more.

Table 15, The most observed type of message on DMS

Type of DMS message	Score
Blank screen	2.36
Travel time	2.97
National celebrations	3.1
Warning messages	3.63
Advisory message	4.41
Road status	4.53

Based on the results found Table 15, participants provide their opinion that the most of the DMSs in Qatar are blank screen, meaning they do not provide any information. This can be due to the fact that most DMS are recently deployed and may not be yet functional, or the fact that a DMS does not need to be showing a message at all time, but only when required based on the real-time situation.

Table 16, Participants preference on pictograms use

Answer Choices	Responses
Text only	9.5%
Pictogram	15.0%
Both text and Pictogram	70.0%
Did not understand the message	5.5%

With regards to the use of pictogram in DMS messages, participants were asked what use can convey the messages, as shown in Table 16. 70.0% believe a combination of text and pictogram is the best use of DMS message. While 15.0% believe the pictogram alone is good enough, 9.5% believed only text message enough. Ma et al. (2014) found that most drivers prefer pictograms to text messages, and the results here are in line with the literature.

Finally, participants were asked to choose the preferred color to be used for the text. Table 17 shows participants responses:

Table 17, Descriptive statistical results of participants opinion about DMS text color

Answer Choices	Responses
Red	11.0%
Green	19.3%
White	42.1%
Yellow	27.7%

Based on the results found in Table 17, 42.1% of participants think white text is easiest to read, followed by yellow with 27.7%, then green with 19.3% and lastly, red color by 11.0%. One of the highlighted points was that the color of the text should not be subject to public debate because the general public aims to aesthetics rather than safety, yellow is best option since it is the most visible under any weather conditions followed by white that might be less visible under foggy conditions. Green and red are not appropriate because they can be assimilated to permission / prohibition like any traffic signal lights.

4.3 ROAD CONDITIONS

Participants were asked 4 questions on their reaction based on a message that contains road questions. Participants’ answers can be summarized in Table *18*. With regards to warning message about accidents ahead, 81.0% participants said that they will reduce the speed based on the message. Also, 61.7% participants said that they will follow the instructions when simply warned about congestion. When the message provided more details about 30 minutes’ delay due to road congestion, the response is relative with 64.7% participants said that they will look for alternative routes. This is in line with previous studies; Guattari et al. (2012) found that providing delay time will affect drivers’ decision. Tunnel fire is a serious situation where drivers need to follow the warnings. 63.8% said that they will exit the road immediately, and 27.3% said they will look for alternative routes.

Generally, it can be concluded that 87.4% of participants trust messages regarding road conditions ahead, regardless if they would follow the message or not.

Participants also highlighted that the warning messages need to provide alternative routes and advise drivers on where to go. Showing that the road ahead is closed is going to create pressure on the drivers and if the driver does not know the alternative route they will reach for their car navigation system or their phone which could result in accidents due to driver panic. This can be easily resolved if the messages provide clear information on alternative routes.

Participants also noted that some DMS signs have too much information and can cause important words to be cut short. For example, "TUNNEL CLOSED FIRE" This is too much information. The message "Tunnel Closed" is all that is required. The word "closed" is the important message and should not be shortened, under any circumstances.

Table 18, *Descriptive statistical results of roads conditions*

Message	Question	Answer Choices	Responses
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	I trust the message and will reduce the speed	81.0%
		I trust the message but will not reduce the speed	10.7%
		I don't trust the message and will not reduce the speed	3.1%
		I require more information to take any decision	5.2%
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	I trust the message and will follow the directions	61.7%
		I trust the message but will not follow the directions	18.7%
		I don't trust the message and will not follow the directions	6.8%
		I require more information to take any decision	12.9%
	If you are approaching a tunnel at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	I trust the message and will exit the road immediately	63.8%
		I require more information to take any decision	8.0%
		I trust the message and will search for alternative route	27.3%
		I don't trust the message and will not follow the instructions	0.9%
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	I trust the message and will change my route	64.7%
		I trust the message but will not change my route	21.5%
		I don't trust the message and will stay on the same route	5.5%
		I require more information to take any decision	8.3%

One technical comment from a participant stated that a DMS can be linked to the Emergency Vehicle Pre-Emption System (EVPS) and response plans for ambulance in case of an emergency that will provide warning messages to drivers such as “Make way for the ambulance” in case one was on the way.

4.4 ROAD CONSTRUCTIONS

Construction work can be seen often on roads in Doha. Participants were asked about regarding their reaction based on a message stating that there are construction works ahead. Summary of participants' responses to road construction messages is shown in Table 19. 71.0% participants said that they will reduce the speed immediately.

Similarly, 66.7% participants said that they will reduce a speed when the message states that the road is under maintenance. 2.8% said that they will not reduce the speed, and 11.8 needed more information to take any decision.

With regards to lane closure, 65.1% said that they will not continue on the same lane and move to the next lane, while 26.2% said that they will reduce the speed immediately to a stationary position.

Lastly, for road closure, participants were shown a message stating that road ahead is closed. 83.8% participants said they will follow alternative route while only 5.3% said they need further information to take any decision.

Generally, it can be concluded that 90.6% of participants trust messages regarding road conditions ahead, regardless if they would follow the message or not. This result is higher from the road condition messages which was 87.4%. Moreover, it is noticed that drivers will comply with the instruction for construction messages more than normal road messages with 78.2% following instructions related to construction work messages, while only 74.6% will follow instructions regarding road and traffic conditions.

Table 19, Summary of road construction responses

Message	Question	Answer Choices	Responses
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	I trust the message and will reduce the speed	71.0%
		I trust the message but will not reduce the speed	22.4%
		I don't trust the message and will not reduce the speed	4.1%
		I require more information to take any decision	2.5%
	If you are driving on a road at a speed of 80 Km/h and you encounter the above message, what will be your reaction?	I trust the message and will reduce the speed	66.7%
		I trust the message but will not reduce the speed	18.7%
		I don't trust the message and will not reduce the speed	2.8%
		I require more information to take any decision	11.8%
	If you are driving on the third lane of a road at a speed of 80 Km/h and you encounter the above message, what will be your reaction?	Reduce speed immediately to stationary position	26.2%
		Require more information to take any decision	7.5%
		Move to the next lane	65.1%
		Nothing	1.3%
	If you are driving on the third lane of a road at a speed of 80 Km/h and you encounter the above message, what will be your reaction?	I trust the message and will change my route	83.8%
		I trust the message but will not change my route	8.4%
		I don't trust the message and will stay on the same route	2.5%
		I require more information to take any decision	5.3%

4.5 WEATHER CONDITIONS

Weather condition messages are used to warn the drivers about rain, fog, heavy wind, etc. Participants were asked about their reaction while driving and encountering weather conditions messages. The participants’ answers are summarized in Table 20.

Table 20, Descriptive statistical results of weather conditions

Message	Question	Answer choices	Responses
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	Reduce speed immediately	59.5%
		Require more information to take any decision	10.7%
		Follow other vehicles' speed	23.9%
		Nothing	5.8%
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	Reduce speed immediately	51.2%
		Require more information to take any decision	12.6%
		Follow other vehicles' speed	22.7%
		Nothing	13.5%
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	Reduce speed immediately	64.4%
		Require more information to take any decision	8.6%
		Follow other vehicles' speed	20.3%
		Nothing	6.8%
	If you are driving on a freeway at a speed of 80 Km/h, and you encounter the above message, what would be your reaction after seeing the message?	Reduce speed immediately	53.7%
		Require more information to take any decision	12.0%
		Change route	28.2%
		Nothing	6.1%

It is noted that 57.2% of participants said that will reduce the speed when warned about weather conditions, while 22.3% of participants choose to follow other vehicles' speeds.

Also, the type of vehicle seems to have effect on driver's decision when it comes to messages about water accumulation. Table 21 compares participants responses on water accumulation based on the type of vehicle they drive on daily basis. It is noticed that Sedan driving vehicles are more likely to change route due to water accumulation than SUV vehicles.

Table 21, Comparison between participants' responses on water accumulation

Vehicle type	Reduce speed immediately	Require more information to take any decision	Follow other vehicles' speed	Nothing
SUV	53.5%	12.9%	24.7%	8.8%
Sedan	50.4%	12.0%	34.4%	3.2%

4.6 GENERAL ADVISORY MESSAGES

Participants were asked about their reaction while driving and encountering the messages shown in Figure 16.

Figure 16, General advisory messages

Summary of participants' responses to general advisory messages is shown in Table 22. With regards to seatbelt message, 91.9% of participants said that they believe the message will remind them or other people to wear seatbelts. Similarly, 87.0% believe that the message will be remind people to stop using the phone while driving.

For speed limit messages, 20.2% participants said that they always follow the speed limit. While 66.2% said the message will remind them to follow the speed limit. With regards to School Zone message, 86.3% said that they will reduce the speed immediately after seeing the message and only 7.1% said that they believe the message is distracting to drivers.

Table 22, Descriptive statistical results of responses to general advisory messages

Message	Question	Answer Choices	Responses
	What is your opinion of the above message?	I wear seat-belt but I believe this message is helpful to others	65.2%
		If I was not wearing the seatbelt, this message will remind me	26.7%
		I don't wear a seat-belt and I believe the message is not useful	5.0%
		Other	3.1%
	What is your opinion of the above message?	I don't use the phone while driving but the message can be useful to others	35.7%
		This message can remind me to stop using the phone while driving	51.2%
		I believe the message is not useful	9.9%
		Other	3.1%
	What is your opinion of the above message?	This message will remind me to follow the speed limit	66.2%
		I always follow the speed limit	20.2%
		I don't follow the speed limit	10.6%
		Other	0.0%
	What is your opinion of the above message?	I believe the message is useful and I will reduce the speed	86.3%
		I believe the message is not useful and I will not reduce the speed	5.9%
		I believe the message is distracting to drivers	7.1%
		Other	0.6%

Lastly, Participants provided some comments on the advisory messages under “Other” option. Some of the comments were provided in Arabic and were translated to English.

The type of messages provided in section 4.6 are not based on current situation but are general to advise drivers on following traffic safety regulations. Some participants stated that showing these messages on DMS can be distracting to drivers or affecting traffic management. However, based on Harms et al. (2018) findings, using traffic irrelevant messages will not affect traffic management. Hence, it cannot be concluded based on participants' opinion that these types of messages will affect traffic management.

With regards to seatbelt messages, some participants stated that the message itself is not helpful to them as they always wear seatbelt, while others stated that it is better to advise on the benefits of wearing seatbelt in the message or reminding the public of the penalty or fine for not wearing a seatbelt.

Similarly, some participants believe that the "DO NOT USE MOBILE WHILE DRIVING" message is useless to them as it is well known to all. It is better to remind people of the fine defined by the traffic police for using the phone while driving.

With regards to speed limit messages, participants highlighted that there is generally no harmony between static speed limit signs, DMS/LCS, and maintenance works signs which is confusing. In addition, there are some signs which appears to be temporary but kept for longer than they should. The result is that these signs give people impression that signs are not real. Furthermore, participants pointed out the fact that people know they pay fines based on static-fixed signs. Moreover, participants highlighted that many drivers only follow speed limit when there is a speed camera, or else they drive based on the road and traffic conditions.

Concerning school zone signs, participants highlighted that these messages need to be timed which school days and not to be shown in all time. That is one benefit of giving general advisory messages in dynamic signs as they can be shown at a specific time. Some participants also stated that a message such as (REDUCE YOUR SPEED / SCHOOL ZONE) is not useful as drivers will go as fast as the speed limit allow which is enforced, but a message advising to reduce speed cannot be enforced.

4.7 CELEBRATION AND GENERAL INFORMATION MESSAGES

Participants were asked about their opinion of celebration and general information messages. Participant responses are summarized in Table 23.

Table 23, Descriptive statistical results of responses to celebration and special events

Message	Question	Answer Choices	Responses
	If you encounter the above message while driving, what is your opinion of the message?	The message provides useful information for road users	10.6%
		Message can be distracting for drivers	25.0%
		Not needed	18.4%
		I like to see this message on the road	45.9%
	If you encounter the above message while driving, what is your opinion of the message?	The message provides useful information for road users	46.3%
		Message can be distracting for drivers	26.6%
		Not needed	9.4%
		I like to see this message on the road	17.8%
	If you encounter the above message while driving, what is your opinion of the message?	The message provides useful information for road users	10.6%
		Message can be distracting for drivers	23.1%
		Not needed	20.3%
		I like to see this message on the road	45.9%
	If you encounter the above message while driving, what is your opinion of the message?	The message provides useful information for road users	12.8%
		Message can be distracting for drivers	19.1%
		Not needed	21.3%
		I like to see this message on the road	46.9%

It is noticed from the responses provided from the participants in Table 23 that generally 39.1% of participants like to see these messages on the road while 23.44% believe these messages can be distracting to drivers. The message providing general information about the live weather information had 46.3% of participants believing that it is useful information.

Lastly, some participants believed that DMS should be used to pass strictly validated traffic related information only. Using them for unrelated and repetitive (daily basis) messages, advertising or celebration messages may distract the users and reduces its importance. The current use of DMS in Doha is less helpful to drivers as most messages are not related to any traffic event but are very general or event-based messages. Participants pointed out that most of the messages shown in the survey have not been seen in Qatar before.

4.8 GENERAL FEEDBACK FROM PARTICIPANTS ON DMS

Finally, Participants were asked to provide any other comments they have related to the topic. Messages related to cultural events should be displayed on DMS with a proper plan where the road safety is not that critical. Also, with regards to the upcoming FIFA World Cup event that will take place in Qatar, DMS should provide information related to the event such as match details (teams playing, score, etc.) and definitely the travel time or expected time to reach based on the current traffic situation.

A major point highlighted by many participants is the fact that ITS is fairly new in Qatar and most drivers do not understand how to react to DMS information. A campaign focused on safety awareness and driver education on the new ITS is important to road safety. Soliman, Alhajyaseen, Alfar, and Alkaabi (2018) studied driver behavior in Qatar and found that there is a need for a comprehensive review of driver education especially with young drivers who will be the main audience for new changes in driving school educational system. Furthermore, tunnels are a new thing in Qatar. Training or sharing information on how to act in the event of an incident and what not to do is equally important to have safe tunnels. DMSs are not included in driving school programs. People are not fully aware about priority possibilities between different signage, or about benefits of DMS.

Participants also noted that some DMS have too much information and can cause distraction especially when there are static directional signs in the same location. Similarly, DMS are deployed in Qatar in very distracting areas or very close to each other in some areas which increases distraction to drivers. A good approach is to have corridors of DMS controls allowing better visibility and direction of traffic flows and information.

Further point highlighted by Arabic speaking participants, is that the message provided different translation from English to Arabic which is not only confusing but also disappointing. Also, the text size/height is very small and difficult to read.

CHAPTER 5: IMPACT OF DMS AND LCS ON DRIVER BEHAVIOR

The second aim of this study is to compare driver behavior in different types of roads when DMS and LCS signs are implemented. The study will focus on three road sections; arterial (route1), freeway with ITS signs (route 2), and freeway without ITS signs. The three routes are shown in Figure 17. The ITS signs that will be used for this study are the DMS and LCS.

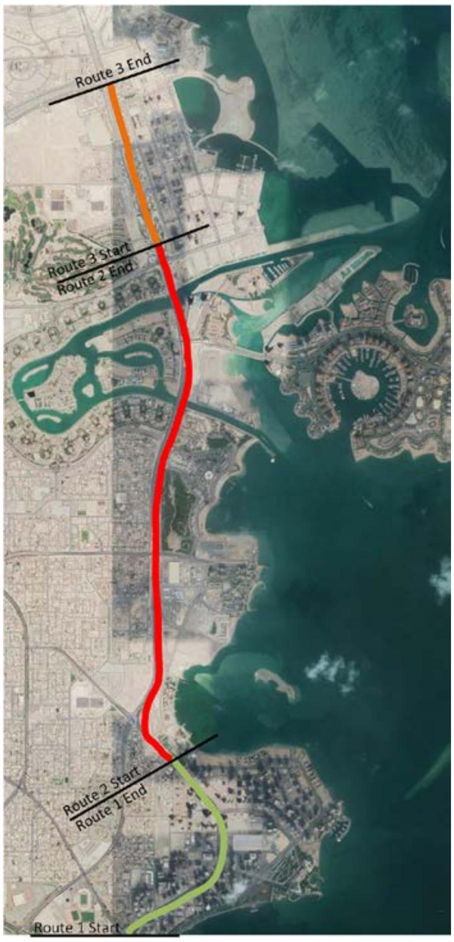

Figure 17, Driving experiment routes

In the driving experiment, a total of 9 variables were measured and compared between the three routes. Table 24 shows a summary of the results from the driving experiment.

Table 24, Descriptive Statistical Results of Driving Experiment

Variable	Indicator	Route 1	Route 2	Route 3
Speed	Driver Average Speed	55.4	98.7	94.3
	Driver Spot Speed	72.6	91.0	93.9
	Flow Speed	70.2	88.9	88.9
	Posted Speed	80.0	80.0	80.0
Lateral Position	Total Length	3.0 Km	5.3 Km	3.2 Km
	% Close to edge	1.5%	1.4%	1.6%
	% Crossing Lane marking	0.3%	0.7%	0.6%
	% Center of the lane	98.2%	97.9%	97.8%
Mental Effort	1*	6.3%	53.1%	62.5%
	2*	28.1%	34.4%	28.1%
	3*	34.4%	12.5%	3.1%
	4*	28.1%	0.0%	0.0%
	5*	3.1%	0.0%	6.3%
	Average Mental Effort	2.9	1.6	1.6
Signs Rating	Poor	28.1%	0.0%	9.4%
	Average	28.1%	0.0%	21.9%
	Good	34.4%	18.8%	53.1%
	Very good	9.4%	81.3%	15.6%
	Score	2.3	3.8	2.8
Lane Changing	No of lane changes	107	123	77
	No of lane changes with Signaling	56	65	27
	No of lane changes without Signaling	51	58	50
	% With Signaling	45.6%	44.3%	63.5%
	% Without Signaling	0.0%	0.0%	0.0%
	Avg. no of incidents per 1 km using signaling	0.6	0.4	0.3
	Avg. no of incidents per 1 km without using signaling	0.5	0.3	0.5
	Avg. no of incidents per 1 km	1.1	0.7	0.7
Recall and Recognition	Speed signs	64.6%	100.0%	53.1%
	Directional signs**	N/A	71.4%	43.3%
	Dynamic Message Signs**	N/A	77.08%	N/A
	Lane Control Signs**	N/A	49.65%	N/A
Signs Following	Speed signs	71.9%	65.6%	53.1%
	Directional signs	25.0%	46.9%	34.4%
	Dynamic Message Signs	3.1%	59.4%	0.0%
	Lane Control Signs	6.3%	84.4%	6.3%
Harsh breaking	no of incident per 1 km	0.16	0.02	0.02
Using of hands on steering wheel	Low Control	31.3%	46.9%	40.6%
	Medium Control	9.4%	25.0%	9.4%
	High Control	59.4%	21.9%	25.0%

* Self-Rated Mental Effort where 1 is the lowest effort, 5 is the highest effort in each route

** Not available on some of the routes

5.1 TRAFFIC FLOW CONDITION

Traffic flow conditions were measure based on observer as well as driver's perception. Table 25 shows the average measured traffic flow conditions for both.

Table 25, Driver vs Observer perception of traffic conditions

Condition	Driver	Observer	Average
Low	56.3%	40.6%	48.4%
Medium	43.8%	59.4%	51.6%
High	0.0%	0.0%	0.0%

Based on the results in Table 25, the traffic flow conditions were mostly considered medium with average estimation 48.4 % for low, and 51.6% for medium and 0% for High level of traffic.

5.2 WEATHER CONDITIONS

Weather conditions in the experiment ranged from normal conditions (clear) to hazy due to dust where visibility was affected. 93.8% of trials were done in normal conditions and 6.3% were done in hazy conditions. No trials were done in rainy condition.

5.3 SPEED

Based on the literature review and the methodology discussed earlier, speeds were measure in three methods. First, the average speed for each participant based on the duration of driving on each route. Second is the spot speed which is the running speed in middle section of each route. Third, is the speed of surrounding vehicles. The speeds were compared with the posted speed. Note that the posted speed for all routes is 80 Km/h. Summary of speed measures are summarized in Table 26 and Figure 24.

5.3.1 DRIVER AVERAGE SPEED

The average speed of each driver was calculated based on the length of the route and the drivers' entry/exit time that was recorded using the GPS Camera. Results are shown in Figure 18.

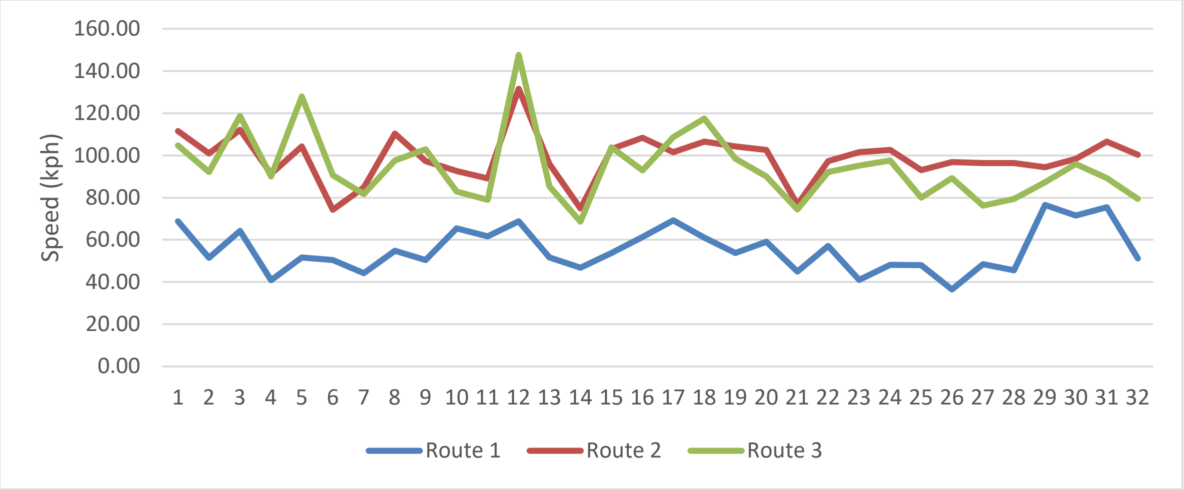

Figure 18, Descriptive statistical results of drivers' average speed

Average speeds for each route are shown in Figure 19.

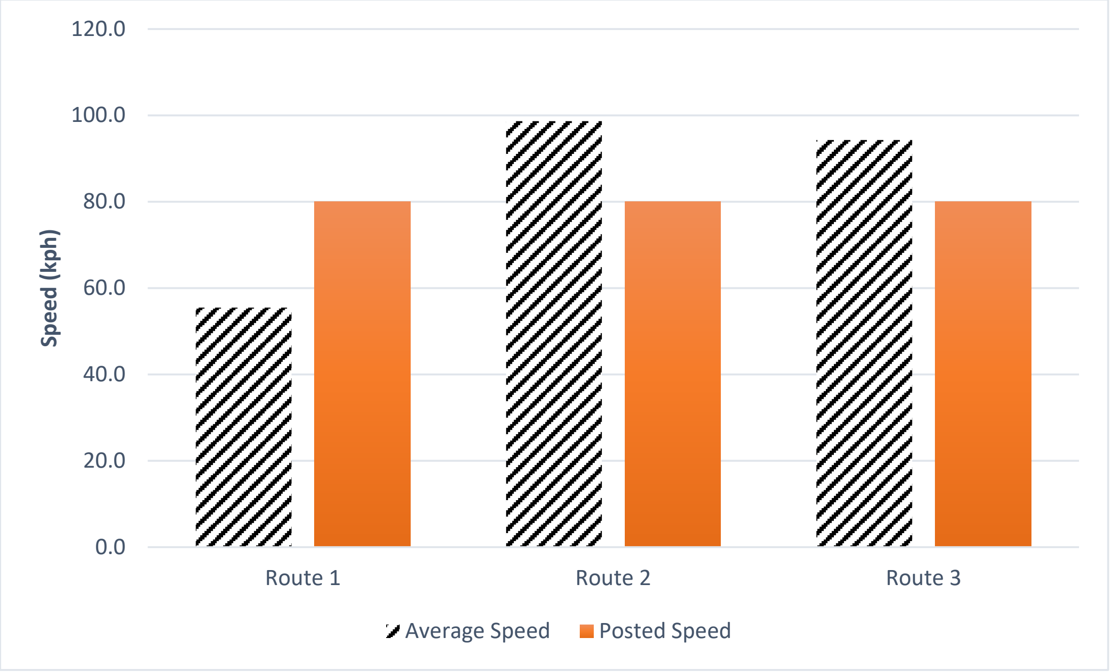

Figure 19, Descriptive analysis of Average Speed for each route

Based on the results shown in Figure 19, it is noticed that the average speeds for route 1 is below the posted speed. On routes 2 and 3, the average speeds are above the posted speed.

5.3.2 SPOT SPEED

Spot speed is a measurement of driver's speed that was measured using the GPS Camera by taking 32 measurements of speed while the vehicle was in motion. This is to counter the impact of stationary stopping at traffic signal intersections in route 1 that would highly affect the average speed as spot in section 5.3.1. Figure 20 shows the average spot speeds for each driver on each route.

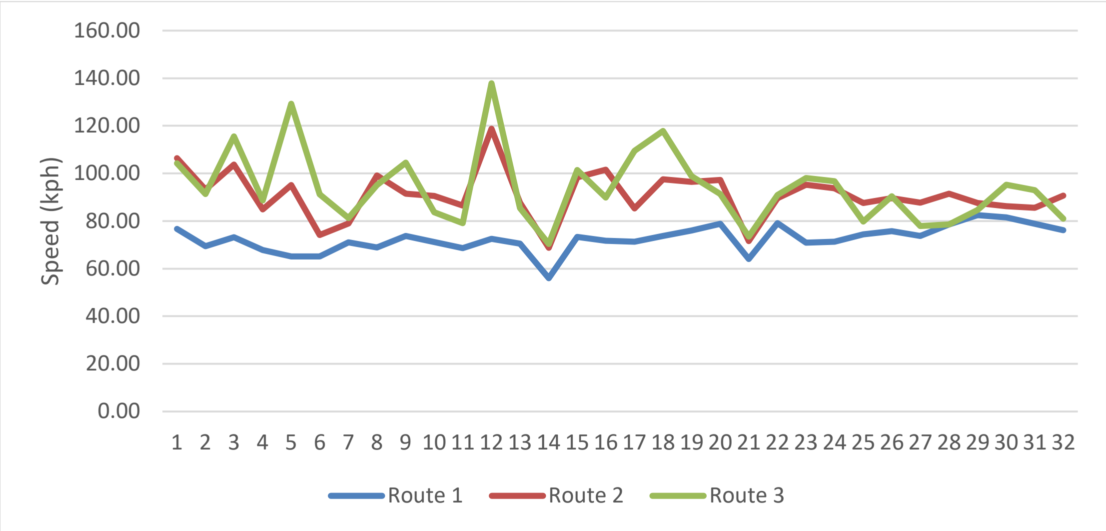

Figure 20, Descriptive statistical results of spot speed

The average spot speeds for each route are compared with the posted speed and results are shown in Figure 21.

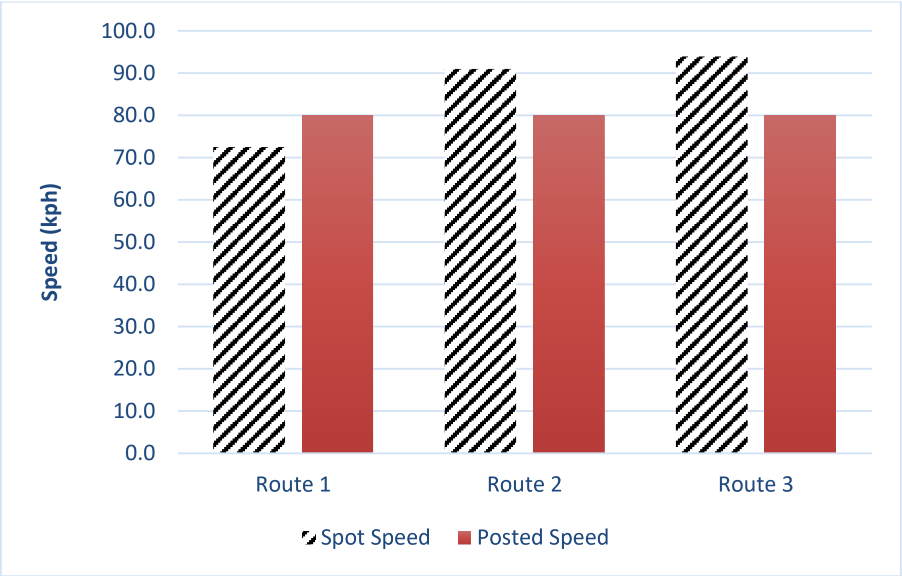

Figure 21, Average Spot Speed

Based on the results in Figure 21, it is noticed than route 1 has average spot speed of 72.6 Km/h with a standard deviation of 5.4 which is 9.3% below the posted speed (80 Km/h). Route 2 has an average spot speed of 91.0 Km/h with a standard deviation of 9.8 which is 13.8% above the posted speed (80 Km/h). Lastly, route 3 average spot speed is 93.9 Km/h with a standard deviation of 15.3 and is 17.4% above the posted speed (80 Km/h).

5.3.3 FLOW SPEED

Flow speed was measured using the remote radar by recording speed of other vehicles. For each trial, 32 measures of speed for other vehicles were taken. Figure 22 shows the average speed for each trial in each route.

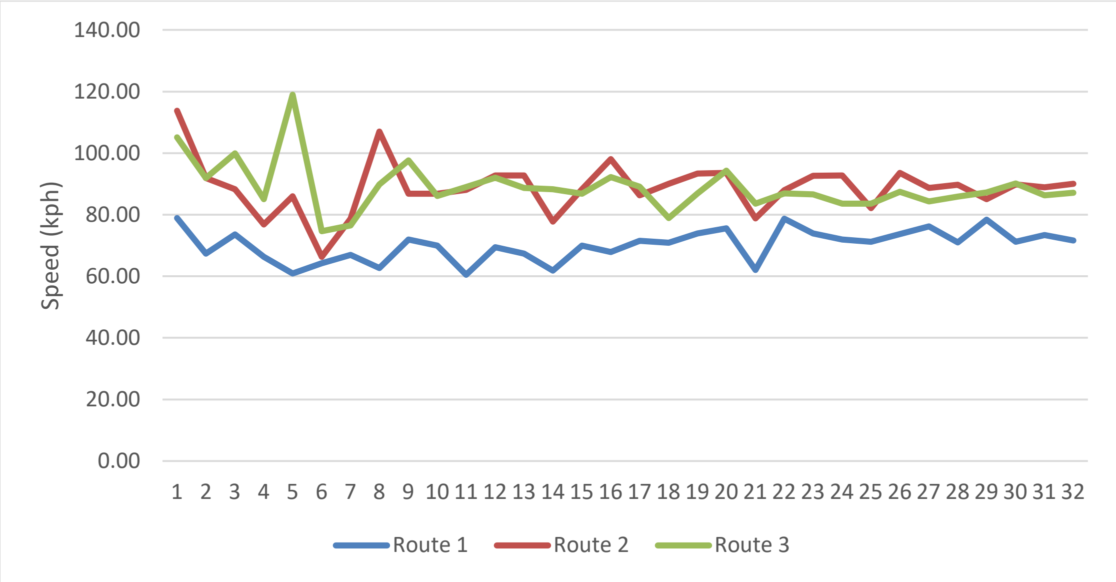

Figure 22, Descriptive statistical results of flow speed

The average flow speeds on each route are shown in Figure 23. Route 1 has average flow speed of 70.2 Km/h with a standard deviation of 5.1 which is 12.3% below the posted speed (80 Km/h). Route 2 has an average flow speed of 88.9 Km/h with a standard deviation of 8.5 which is 11.1% above the posted speed (80 Km/h). Lastly, route 3 average flow speed is 88.9 Km/h with a standard deviation of 8.2 and is 11.1% above the posted speed (80 Km/h).

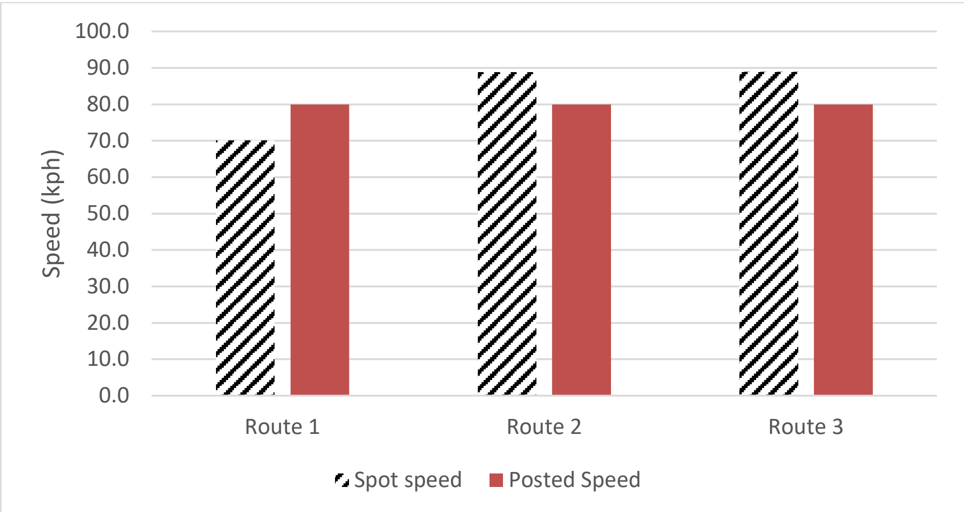

Figure 23, Average Flow Speed

5.3.4 SPEED SUMMARY

The results of speed measurements are summarized in Table *26* and Figure 24.

Table 26*, Speed summary for each route*

Route	Average speed	Spot speed	Flow speed	Posted Speed
Route 1	55.4	72.6	70.2	80
Route 2	98.7	91.0	88.9	80
Route 3	94.3	93.9	88.9	80

Figure 24, Summary of variable speed results

It is noted that on route 2 and 3, the average speed is close to the spot speed. However, as expected, there is a great difference on route 1 since it includes traffic signal intersections.

For route 1, drivers' average speed, spot speed, and flow speed are below speed limits. Based on the methodology used for calculating each value, it is expected that the average speed will be lower than the spot or flow speed since it counts for vehicle stopping at the traffic signal intersections. Table 27 shows percentage of average, spot, and flow speeds out of the posted speed for each section.

Table 27, Comparing the speeds with posted speed

Speed	Route 1	Route 2	Route 3
Driver Average Speed	69.3%	123.4%	117.9%
Driver Spotted Speed	90.7%	113.8%	117.4%
Flow Speed	87.7%	111.1%	111.1%

It is noted that on Route 1, all measured speeds are below the posted speed , while on routes 2 and 3, speeds are surpassing the posted speed of 80 Km/h. Therefore, it is concluded based on the results of the driving experiment that the existence of DMS and LCS had no effect on drivers' speed compliance. Although it was found in the literature review that these signs reduce over-speeding occurrences (Xu et al., 2018), the drivers' compliance in Qatar is not affected by these signs.

5.4 HARSH BRAKING

The number of harsh braking incidents were recorded in each trial. Table 28 shows the average number of harsh braking incidents on each route. Since the routes have different length, the average number of harsh braking incidents were divided by the total length of each route in km.

Table 28, No. of harsh braking incidents

	Route 1	Route 2	Route 3
Average	0.47	0.09	0.06
SD	0.62	0.30	0.25
Average per 1 km	0.16	0.02	0.02

As shown in Table 28, the average numbers of harsh braking incidents on each route were insignificant. Although route 1 have slightly larger number with 0.156 incident per 1 km.

5.5 LANE CHANGING

Lane changing was recorded with and without using turn-signaling indicator as shown in Table 31.

Table 29, Number of lane changing occurrences

Turn-Signaling Indicator	Route 1	Route 2	Route 3
With Signaling	56	64	27
Without Signaling	47	51	47
Total number of lane changes	103	115	74
Average number using Signaling	1.8	2.0	0.8
Average number without using Signaling	1.5	1.6	1.5
Average number of lane changes	3.2	3.6	2.3
% With Signaling	54.4%	55.7%	36.5%
% Without Signaling	45.6%	44.3%	63.5%

It is noticed that lane changes occurred mostly on route 2 with an average of 3.6 lane changes occurrences. However, since the three routes do not have the same length, the average number of lane changes was calculated per 1 km. Descriptive statistical results are shown in Table 32.

Table 30, Average number of Lane changing occurrences per 1 KM

Turn-Signaling Indicator	Route 1	Route 2	Route 3
With Signaling	0.6	0.4	0.3
Without Signaling	0.5	0.3	0.5
Total	1.1	0.7	0.7

The results shown in Table 32 is completely different than it was in Table 31. It is concluded that Route 2 has the lowest number of lane changes (LC) per 1 km, followed by route 3, then route 1.

Also, from the above results, the use of turn-signaling indicator was recorded, and it is noted that turn signaling was mostly used on Route 1 and 2 with 54.4% and 57.7% respectively. However, on route 3, it was used only 36.5% of the times.

Summary of the use of turn-signaling indicators is shown in Table 31.

Based on the results shown in Table 31 and Table 32, it is concluded that route 2 had the lowest number of lane changes per 1 km, and the highest number of turn-signaling indicator.

5.6 LATERAL POSITION

Vehicle lateral position was recorded. Descriptive statistical results are shown in Table 35.

Table 31, Descriptive statistical analysis of lateral position

Column1	Route 1	Route 2	Route 3
Total Length	3.0 Km	5.3 Km	3.2 Km
% Close to edge	1.5%	1.4%	1.6%
% Crossing Lane marking	0.3%	0.7%	0.6%
% Center of the lane	98.2%	97.9%	97.8%

Based on the results shown in Table 35, it is noted that Route 3 has the highest deviation of driving vehicle from the center of the lane with 1.6% close to edge and 0.6% crossing the lane marking. Route 2 has the highest percentage of length crossing the lane with 0.70%.

5.7 POSITION OF THE HANDS ON THE STEERING WHEEL

Position of drivers' hands on steering wheel were recorded and classified as explained in Section 3.2.4.9. The result is summarized in Table 36.

Table 32, Results of hands position on the steering wheel

Control Level	Route 1	Route 2	Route 3
Low Control	31.3%	46.9%	40.6%
Medium Control	9.4%	25.0%	9.4%
High Control	59.4%	21.9%	25.0%

Based on the results shown in Table 36, it is perceived that route 1 had the highest control for drivers with 59.4% are in High Control position. On the contrary, Route 2 had the lowest percentage of drivers using High Control position with only 21.9%. This indicates that drivers felt more comfortable driving on route 2.

5.8 SELF-REPORTED MENTAL EFFORT

Self-reported mental effort was recorded based on driver's opinion. Descriptive statistical results are shown in Table 37.

Table 33, Self-reported mental effort on each route

SRME	Route 1	Route 2	Route 3
1	6.3%	53.1%	62.5%
2	28.1%	34.4%	28.1%
3	34.4%	12.5%	3.1%
4	28.1%	0.0%	0.0%
5	3.1%	0.0%	6.3%

It was found that route 1 has the highest SRME with a mean of 2.9 and SD of 1.0, while route 2 and 3 had the same average SRME of 1.6 and SD 0.7 for route 2 and 1.0 for route 3.

The SRME values for routes 2 and 3 are the same and lower than route 1. This could be due to the fact that route 1 is an arterial road with more traffic, traffic signal intersection, etc. However, both route 2 and 3 are freeways.

5.9 TRAFFIC SIGNS RATING

Drivers were asked to rate the signs used on each route based on how useful they were to the driver. The rating used the following scale (poor – average – good – very good). Results are shown in Table 40.

Table 34, Signs rating for each route

Rating	Route 1	Route 2	Route 3
Poor	28.1%	0.0%	9.4%
Average	28.1%	0.0%	21.9%
Good	34.4%	18.8%	53.1%
Very good	9.4%	81.3%	15.6%

In order to get the average rating for each route, options were rated from 1-4, 1 being lowest (poor), and 4 being the highest (very good). Based on this analysis, signs were rated as shown in Table 41.

Table 35, Average ratings for each route

Section	Rating
Route 1	2.3
Route 2	3.8
Route 3	2.8

Based on the results in Table 41, Route 2 has the highest rating of 3.8, followed by Route 3 with rating of 2.8, and finally Route 1 with a rating of 2.3.

The results of the traffic signs rating are corresponding to the results in section 5.8 and confirms it.

5.10 RECALL AND RECOGNITION

Drivers were asked in the post-trip questionnaire to recall how many signs they have witnessed while driving on each route. Results are summarized in Table 44.

Table 36, Traffic signs recall

	Route 1		Route 2		Route 3	
	Actual	Average	Actual	Average	Actual	Average
Speed Signs	3.0	1.9	2.0	2.0	3.0	1.6
Directional Signs	0.0	0.9	6.0	4.3	7.0	3.0
Dynamic Message Signs	0.0	0.0	3.0	2.3	0.0	0.0
Lane Control Signs	0.0	0.0	18.0	8.9	0.0	0.0

From the results shown in Table 44, it is noticed that Directional signs were recalled in route 1, while there were not any actual directional signs on that route. DMS is the most accurate recalled sign with an average of 77.1% of the actual number. Similarly, Speed signs average recall was 72.6% of the actual. Summary of the recall accuracy is shown in Table 45.

Table 37, Recall accuracy

Type of sign	Route 1	Route 2	Route 3	Average
Speed signs	64.6%	100.0%	53.1%	72.6%
Directional signs	N/A	71.4%	43.3%	57.3%
Dynamic Message Signs	N/A	77.1%	N/A	77.1%
Lane Control Signs	N/A	49.7%	N/A	49.7%

5.11 COMPLIANCE BEHAVIOR

From the post-trip questionnaire, drivers were asked if they think they have followed the different signs on each route. Results are summarized in Table 46. Note that Dynamic Message Signs and Lane Control Signs were found only in Route 2. Hence, there is no data for compliance on route 1 and 3.

Table 38, Drivers compliance for different type of signs

Type of Sign	Route 1	Route 2	Route 3	Average
Speed signs	71.9%	65.6%	53.1%	63.5%
Directional signs	N/A	46.9%	34.4%	40.6%
Dynamic Message Signs	N/A	59.4%	N/A	59.4%
Lane Control Signs	N/A	84.4%	N/A	84.4%

Based on results in Table 46, LCSs are the most followed type of signs with an average of 84.4% being followed. Schaefer et al. (1998) found that drivers' compliance to LCS are higher in low to medium traffic conditions. As found earlier in section 5.1, all experiment drives were conducted on low to medium traffic conditions. With regards to speed limit signs, they are the second most followed signs. It is noticed that speeds signs are less followed in route 3 than in route 1 and 2 with 71.9% on route 1, 65.6% on route 2, and 53.1% on route 3. It is noted that route 2 and 3 are the same type of highway and an extension of each other. The only difference between route 2 and 3 are the presence of ITS, mostly DMS and LCS. Comparing this with the results found in section 5.8, this could relate to why drivers did not follow speed limit signs due to drivers feeling safe in the route. With regards to DMS and directional signs, they were followed by 59.4% and 40.6% respectively of all times.

With regards to speed compliance, average speeds were below the speed limit on route 1, and route 2. There are over-speeding incidents that was reported on all routes. However, results found that the average speeds on route 3 are above the speed limit of 80 Km/h. It’s noted that only route 1 is enforced with speed cameras.

CHAPTER 6: Discussion and Conclusion

6.1 DISCUSSION ON DRIVERS' PERCEPTION OF DMS

With regards to Socio-economic characteristics of the participant sample, the study evaluated if these characteristics will affect the results. It was found that there is no main variable that have noticeable effect on the results.

According to the survey, it is found that most of the participants are familiar with the DMS in Qatar with only 2.0% of the sample stating they haven't seen a DMS before. What was noted, that based on the survey questions, a number of participants highlighted that many DMSs are not providing information based on real-time current event and most of DMS screens are blank. With regards to message content, participants preferred using white text and combining text with pictogram. These results were similar to Lee et al. (2004) findings that participants prefer the use of pictograms with text.

DMS that are providing information about road conditions; i.e., Accident ahead, Congestion Ahead, Tunnel Closed, and Delay time, results showed that 87.4% of the participants tend to trust the information provided in the message and, subsequently, 67.8% participants stated that they will follow the message. Guattari et al. (2012) studied the effect of DMS on road safety and found that it has a positive impact. It was also found in this study that stating the delay time will affect drivers' decision to change route in case of traffic congestion ahead.

Construction works are common on the roads of Doha due to city high expansion rate. Messages related to construction and maintenance works are found to be more effective in compliance rate compared with road and traffic condition messages with 90.6% of participants stating they will follow the instructions related to construction works ahead.

With regards to weather conditions and environment related messages, 57.2% of participants stated that they will reduce the speed based on the DMS messages. Results also show that sedan drivers are more likely to change route when informed about water accumulation in a DMS message.

DMS that are showing general advisory statements such as; “FASTEN YOUR SEAT BELT”, “DO NOT USE MOBILE WHILE DRIVING”, “FOLLOW SPEED LIMIT”, etc., have positive effect on driver’s behavior with majority of participants stating that the message can remind them or others of using the seatbelt, not using the phone, and following speed limit with 91.9%, 86.9%, and 66.2% respectively. Nevertheless, participants highlighted that there seem to be no harmony between maximum allowed speed shown on dynamic signs with static fixed signs, and in most cases, drivers will only follow static one as they believe they will be fined based on this speed when over-speeding. With regards to school zone related messages that remind driver to reduce the speed, 86.3% of participants think this the message is useful. However, it should be timed to school days and school hours. This is one of the main advantages of having a dynamic sign that it can be changed automatically on specific times, or remotely from a control center.

Regarding celebration and special events messages that are shown on DMS, participants had mixed opinions with an average of 11.3% believing the message is useful, and 46.2% stated they like to see this type of messages. On the other hand, 22.4% stated that these messages can be only distracting to drivers and 20.0% think the message is not needed. Overall, it was found that 46.2% like to see these messages on the road. With regards to whether showing these types of messages would affect other traffic warning messages, Harms et al. (2018) assessed driver behavior in responding to a critical route instruction message displayed on a DMS that previously displayed a variety of traffic-irrelevant messages and concluded that it did not affect driver behavior when shown critical instruction.

Finally, it was found based on participants' preference survey, that General Advisory Messages are the most preferred messages by the participants with 82.8% likely to see or will follow the message, followed by Road Construction messages with 78.2%, followed by Road Condition messages with 74.6%, followed by Celebration messages with 59.2% and finally, Weather Condition messages with 57.2%.

6.2 DISCUSSION ON IMPACT ON DRIVER BEHAVIOR

Speed was measured in three methods; average speed, spot speed, and flow speed. Route 1 is an urban arterial road with three traffic signal intersections, while route 2 and 3 have the same classification as urban freeway. However, route 2 is supported with ITS infrastructure including DMS and LCS while route 3 does not include any ITS elements. Due to the road layouts and classifications, the computed average speed in route 1 is lower than routes 2 and 3 which is caused by the vehicle stopping at intersections. Hence, average speed is highly different from spot speed and flow speed. Because flow speed was measured at midpoints between two intersections in route 1 and to counter this effect, spot speed was introduced. Overall, drivers were below the maximum allowed speed (posted speed) on route 1. For the freeway section, participants' average speed and traffic flow speed on route 2 and 3 were above the posted speed. It is important to note that route 2 and 3 are not speed enforced, while route 1 is enforced using speed cameras. Previous studies have demonstrated that DMSs have a positive effect on drivers' compliance to speed. Xu et al. (2018) found that introducing DMSs on the same corridor can reduce over speeding occurrences. However, in this study, it was found that the introduction of LCS and DMS had no effect on speed compliance.

With regards to lane changing, results showed that route 2 has the lowest number of lane changes occurrences per kilometer. But the result in route 2 is very close to route 3. Hence, the implementation of LCS had no effect lane changing. However, the use of turn-signaling indicators was recorded, and results show that drivers were using signaling most on route 2, followed by route 1, then route 3, with 55.7%, 54.4%, and 36.5% respectively. Therefore, it can be concluded that the introduction of LCS and DMS had positive effect on traffic safety.

Journey comfort is an important element that was compared between the three routes. Comparison was made with regards to number of harsh braking incidents, hand position on steering wheel, Self-reported mental effort, and participant rating of traffic signs. Harsh breaking was found to be most on route 1, followed by route 2 and 3. Results show that there is no significant difference between route 2 and 3 and hence, it is concluded that DMS and LCS had no effect on harsh breaking. Refer to Table 28 on the number of harsh breaking incidents per kilometer on each route.

Position of the hands can indicate the driver comfort. According to the route 2 had the lowest percentage of “High Control” position, followed by route 3, then route 1. Also, driver’s opinion and self-reporting was considered. Route 2 and route 3 had the same SRME of 1.6 which were lower than route 1 which was 2.9. Hypothesis analysis found no significant difference between routes 2 and 3. Therefore it is concluded that DMS and LCS signs had no effect on mental effort. Finally, participants rated the traffic signs. Hypothesis testing conclude that the rating for three routes are different. Route 2 was rated highest with an average of 3.8 followed by Route 3 with rating of 2.8, and finally Route 1 with a rating of 2.3 out of 5.

Lastly, participants' self-reported compliance on following traffic signs instructions was recorded. Results show 59.4% of participants stated they followed DMS instructions, while 84.4% followed LCS signs. These results are in line with the findings of previous studies. Schaefer et al. (1998) found that LCS will be beneficial on low and medium traffic conditions. In this experiment, all driving attempts were conducted on low and medium traffic conditions. Furthermore, Wu and Liang (2016) found that a well-placed DMS can increase drivers' compliance and reduce the travel time. With regards to speed static signs, an average of 63.5% of participants following in all three routes. It is noted that speed limit signs compliance was higher on route 1. Shaaban and Pande Shaaban and Pande (2018) stated that speed cameras on intersections in Qatar increase driver compliance. Furthermore, 40.6% of participants stated they followed directional signs. In conclusion, drivers tend to follow dynamic signs more than static signs.

6.3 LIMITATIONS

The study has used two methods of data collection to overcome some of the limitations found in each method. With regards to the online survey, the primary limitation is that the questions can never imitate real-life scenarios since the participant will have long time to answer.

The driving experiment was aimed to evaluate driver behavior with DMS and LCS signs, and compare the behavior with other two types of roads. However, the experiment was limited by the following:

- The chosen route is fairly new and may not have all the functions of DMS and LCS currently in operation.

- The participants were not using their own vehicles, and which may have an effect on their driving behavior since they are new to the vehicle.
- Since this is not a simulation, there is no control over the dynamic messages were based on the signs at the time of the experiment.

6.4 RECOMMENDATIONS

This study provides a number of recommendations to the road authorities, and for future research work.

6.4.1 RECOMMENDATION TO AUTHORITIES

Currently, Public Works Authority is responsible for the design, implementation and maintenance of ITS works in Qatar. In the future, some of the responsibilities may shift to the Ministry of Transportation and Communications. Based on the results of this study, the following recommendations are highlighted to the road authorities in Qatar.

Participants highlighted that they were not aware of some of the DMS functions before they take the survey. This is caused by the limited usage of DMS functions currently in Qatar. Most DMS are not providing real-time current information. Furthermore, participants highlighted that many of the DMSs are blank and they believe they should be operating. It’s recommended to authorities to consider reviewing the current operation of DMS, and to check if they are operating as planned. In locations where road safety or traffic operation is critical, it is recommended that the DMS are only providing traffic-related information.

For the layout of the DMS message, it is noted to the authority that based on participants’ preference in the online survey, that they preferred white and yellow colors for the characters in messages and the combination of text with pictograms.

With regards to warning message about congestion or accident ahead, authorities should consider providing road users with alternative routes. It is also recommended that the DMS provide delay time information when advised about a congestion ahead.

It is also recommended to the authorities to check the operating DMS for any incorrect displayed information as keeping wrong message may affect drivers' trust for DMS information.

Another recommendation is to consider linking the DMS message to EVPS system for emergency vehicles. DMS can advise drivers earlier about an incident and make way for approaching emergency vehicles.

When it comes to maximum allowed speed, there should be harmony between static and dynamic at the moment. In case of conflict, traffic laws need to be clear on which speed to follow. Furthermore, it is recommended that the authorities check and remove the duplication between static and dynamic to avoid confusion among drivers.

Since ITS is expanding in the country, the government should host educational campaigns focused on safety awareness and driver's education on the new ITS systems. Currently, part of the driving population in Qatar does not know about DMS functions and how to react to its messages. It is recommended to the authorities to include DMS and LCS messages in driving school to prepare new drivers, and host education campaigns to share the knowledge with existing drivers.

With regards to the co-location of different type of signs at the same location, i.e., DMS, LCS, and Direction signs on the same gantry, it is recommended to the authorities based on participants' feedback to review and regulate the maximum allowed number of signs as too much information may have negative effect and confuse drivers.

6.4.2 RECOMMENDATION FOR FUTURE RESEARCH

For future research works, the following topics needs to be explored further.

The driver behavior in this study focused on one corridor. Future studies should consider different locations and other types of roads. This study was conducted on Lusail expressway, which is constructed with a high level of ITS implementation. Some other roads may have a lesser level of ITS deployment, i.e., only DMS or LCS is deployed, different sizes of DMS, or less frequency of LCS sets. As the level of ITS may have an impact on the behavior of drivers, future work may study and compare driver behavior in different levels of ITS implementation.

It is also recommended that ITS signs be studied in Qatar in the future as ITS will be more mature and drivers will be more familiar with the new road technologies.

Also, studies need to compare traffic-related information, i.e., traffic condition ahead, when provided by a DMS or by the car navigation system or mobile phone applications. It is important to know which method is better or more trustworthy source to the drivers.

Co-location of too many dynamic and static signs on the same gantry has been highlighted as undesirable. However, it is not clear what is the amount of information that can be provided to the drivers and maintain a safe environment. Future studies can quantify the number of information and also study the desired text height.

Other ITS systems such as detectors or cameras can be utilized for future research about DMS and LCS compliance behavior.

Last but not least, similar studies about driver behavior with respect to DMS and LCS signs in GCC or MENA region needs to be conducted.

6.5 CONCLUSION

Intelligent transportation systems are the future of transportation. Many countries are shifting into implementing ITS in their cities. The state of Qatar has invested billions of dollars into building a state of the art ITS system. Many studies have been done on driver behavior with the deployment of intelligent electronic signs in Europe, East Asia, and North America regions. However, there aren't many studies on how effective ITS systems are in the Middle East and North Africa region.

The aim of this study is to review the public perception of DMS signs in Qatar. In addition, this study also compared driver behavior in three different types of roads where one section has both DMS and LCS signs implemented.

In this study, the drivers' perception of dynamic message signs was assessed using an online questionnaire to capture people's perception of dynamic message signs messages. 402 people participated in the survey which included 7 parts; personal questions, general questions on DMS, road conditions messages, road construction messages, weather conditions messages, general advisory messages, celebration and special events messages.

Secondly, a driving experiment was conducted with 32 participants to study the driver behavior. The driving experiment consisted of three routes with a total of 11.5 kilometers. Route 1 is a 3-km arterial road with 4 traffic signal intersections. Route 2 is a 5.3-km freeway with 3 DMS, and 17 LCS deployed on the road. Route 3 is a 3.2-km freeway with no ITS.

Results of this study show that most drivers like to see advisory messages and will respond to DMS warning messages about construction works or road and traffic conditions. However, with regards to celebration and special event messages that are shown on a DMS, some drivers support this type of message while others think they are not useful and distracting. Finally, weather condition messages were found to be the least followed type of messages based on the survey.

Furthermore, based on the driving experiment results, it can be concluded that the introduction of DMS and LCS had no impact over speed compliance. With regards to journey comfort, it is concluded based on the analysis that the LCS and DMS did not have real effect on some driver behavior variables such as harsh breaking, lane changing but was beneficial in drivers' opinion and driver behavior in steering wheel control level.

Additionally, it was found that drivers' compliance was highest towards LCS, followed by speed limit signs, then DMS, then static directional signs. This study also concluded that drivers will follow static speed limit signs when there is a contradiction between the static and dynamic signs.

Finally, the study also provided a number of recommendations to the government road authorities with regards to deployment of DMS and LCS. In addition, the study also highlighted a few topics for future research work.

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