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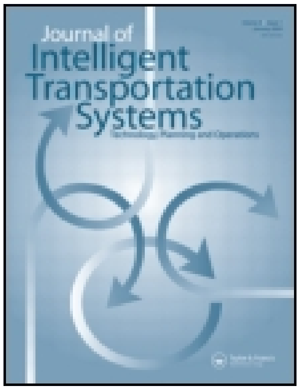

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Driver Behavior and Preferences for Changeable Message Signs and Variable Speed Limits in Reduced Visibility Conditions

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Driver Behavior and Preferences for Changeable Message Signs and Variable Speed Limits in Reduced Visibility Conditions

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This article investigates the factors affecting drivers' stated behavior in adverse visibility conditions and examines whether drivers rely on and follow advisory or warning messages displayed on portable changeable message signs (CMS) and/or variable speed limit (VSL) signs in different visibility and traffic conditions, and on two types of roadways: freeways and two-lane roads. A multiple-approach survey was designed to collect opinions and stated data from Central Florida drivers. Categorical data analysis techniques such as conditional distribution, odds ratio, and chi-squared tests were applied. In addition, two modeling approaches, bivariate and multivariate probit models, were estimated. The results revealed that gender, age, road type, visibility condition, and familiarity with VSL sign were the significant factors affecting the stated likelihood of reducing speed following CMS/VSL instructions in reduced visibility conditions. Other objectives of this study were to determine the content of messages that would achieve the best perceived safety and drivers' compliance and to examine the best way to improve safety during these adverse visibility conditions. The results indicated that respondents thought that "Caution–fog ahead–reduce speed" was the best message and that using that CMS and VSL signs together was the best way to improve safety during such inclement weather situations. Based on the findings of the present study, several recommendations are suggested as guidelines to improve safety in reduced visibility conditions.

Keywords Changeable Message Signs; Variable Speed Limit; Reduced Visibility; Driver Behavior; Probit Model

INTRODUCTION

Inclement weather events such as fog/smoke (FS), heavy rain (HR), high winds, and so on affect every road by impacting pavement conditions, vehicle performances, visibility distances, and drivers' behavior. Moreover, they affect travel demand, traffic safety, and traffic flow characteristics. Visibility in particular is critical to the task of driving, and reduction in visibility due to FS or other weather events such as HR is a major factor affecting safety and proper traffic operation. Data queried from the Fatality Analysis Reporting System (FARS) show that 3,729 fatal crashes that occurred in the United States between 2000 and 2007 were mainly due to the FS factor. Florida was the third state, after California and Texas, in fatal crashes due to FS with 299 fatal crashes. Although the percentage of FS-related crashes is small compared to crashes that occurred at clear visibility conditions, these crashes tend to be more severe and involve multiple vehicles. The most recent example of fog-related crashes happened in Florida was on I-4 in Polk County in January 2008, resulting in a 70-vehicle pile-up. This multivehicle crash caused five fatalities, many injuries, and shutting down I-4 for extended time.

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Thus, there is a need to detect any reduction in visibility and develop ways to convey warnings to drivers in an effective way. A real-time measurement of visibility and/or understanding drivers' responses when the visibility falls below certain acceptable level may be helpful in reducing the chances of visibility-related crashes.

This study aims at gaining better understanding of drivers' likely behavior under different visibility and traffic conditions over a freeway (representing divided multilane facilities) and a two-lane road. The data used for analysis were obtained from a self-reported questionnaire survey carried out for 566 drivers in Central Florida. Different survey forms were designed to reflect the two roadway types. The survey was delivered using multiple approaches: handout, interactive, and online questionnaires.

To achieve the objectives of this survey, different scenarios consisting of several visibility levels, traffic conditions, CMS, and VSL signs were designed using driving simulation software, the L-3 Scenario Editor. There is no doubt that it would have been better to use real pictures in this study. However, the Scenario Editor software was used because it was not possible to find real pictures for all the scenarios. Snapshots at different fog levels, traffic conditions, and covering the two roadway types were prepared before designing the two survey forms. It is worth mentioning that due to limited budget and the various scenarios that were investigated in this study, neither field studies nor driving simulator experiments were feasible. To sum up, research issues investigated in this article are:

1. Whether drivers follow warning messages displayed on CMS and/or VSL signs in adverse visibility conditions and rely on such messages.
2. Drivers' stated responses to different visibility conditions.
3. What differentiates drivers who claim to be more or less likely to comply with CMS and VSL signs instructions?
4. What is the content of warning messages that would achieve the best perceived safety and driver stated compliance in reduced visibility conditions?
5. What are the options that would be preferred during driving through FS: using CMS only, using VSL signs only, using both CMS and VSL signs together, or closing the road during such adverse visibility conditions?
6. What are the differences in drivers' responses to reduction in visibility for freeways versus two-lane roads?

BACKGROUND

Drivers' responses to both traffic and environmental conditions can be examined through a variety of approaches, including questionnaire surveys, driving simulator experiments, and network monitoring. The relatively low cost of questionnaire surveys, compared to the other approaches, has encouraged researchers to use it as a way to collect data on different driving situations under different traffic and environmental conditions (Chatterjee, Hounsell, Firmin, & Bonsall, 2002).

In general, there are two kinds of questionnaires: a stated preference (SP) survey, examining human response to a hypothetical situation, and a revealed preference (RP) survey, investigating human response derived from a real-life choice situation in the physical world.

The primary shortcoming of SP data is that they might not be harmonious with actual behavior. The issues of realism, task complexity, familiarity, tendency to exaggerate, and strategic bias (i.e., when the respondent provides a biased answer in order to influence a particular outcome) are the main reasons for their inconsistency with revealed preferences data (Lu, Fowkes, & Wardman, 2008).

A number of prior studies examined consistency between RP and SP data. By comparing SP data to actual trip data, Loomis (1993) found that SPs relating to intended trips under alternative quality levels are valid and reliable indicators of actual behavior. Cummings, Harrison, and Rutstrim (1995) compared real purchasing behavior for private goods with dichotomous choice (DC) contingent valuation questions. They found that the proportion of DC "yes" responses exceeds the proportion of actual purchases. Also, Johannesson, Liljas, and Johansson (1998) showed that hypothetical "yes" responses overestimate the real purchases. Yannis, Kanellopoulou, Aggeloussi, and Tsamboulas (2005) indicated that some participants may have the tendency to exaggerate when they respond to SP questions, and hence, more attention should be given to the results explanation and conclusions.

Despite those drawbacks, questionnaire surveys have been commonly used so far to study drivers' responses to Advanced Traveler Information System (ATIS) and to adverse weather conditions. Clearly, the surveys can provide valid results and indications. However, actual magnitude of these results should be viewed carefully and interpreted conservatively.

The SP surveys have been widely adopted in numerous transportation studies. Abdel-Aty, Vaughn, Kitamura, Jovanis, and Mannering (1994), Khattak Polydoropoulou, and Ben-Akiva (1996), Mahmassani, Huynh, Srinivasan, and Kraan (2003), Iragüen and Ortúzar (2004), Tilahun, Levinson, and Krizek (2007), Junyi, Akimasa, and Soe (2008), Carlsson, Daruvala, and Jaldell (2010), and Correia and Viegas (2011) used the SP method to identify the behaviors of drivers with ATIS deployments.

Drivers' Responses to ATIS

Many previous studies focused on studying commuters' behavior, responses and satisfaction with Intelligent Transportation Systems (ITS) such as Harris and Konheim (1995), Benson (1996), Emmerink et al. (1996), Abdel-Aty et al. (1994; Abdel-Aty, Jovanis, & Kitamura, 1996; Abdel-Aty, Kitamura, & Jovanis, 1997), Peeta, Ramos, and Pasupathy (2000), Chatterjee et al. (2002), Ng, Cheu, and Lee (2006), Neale, Perez, Lee, and Doerzaph (2007), Tsirimpa and Polydoropoulou (2007), Chorus, Arentze, and Timmermans (2007), and Lee, Ran, Yang, and Loh (2010).

For example, Abdel-Aty et al. (1996, 1997) examined the effects of advanced transit information systems on commuters' willingness to use transit. Ng et al. (2006) evaluated the effect of real-time traffic information (i.e., using variable message signs and travel time displays) on the average truck travel time when an incident occurs en route. Neale et al. (2007) evaluated drivers' responses to signalized and stop-controlled violation warning systems (also see Viti & van Zuylen, 2009). Tsirimpa and Polydoropoulou (2007) examined the impact of information acquisition through ATIS on switching travel behavior. Chorus et al. (2007) investigated drivers' needs for specific types of travel information. Lee et al. (2010) examined the factors affecting drivers' route choice behavior.

In addition, a number of earlier studies have used images of CMS to explore driver comprehension and responses to the information displaying on CMS. For instance, using an SP survey, Wardman, Bonsall, and Shires (1997) evaluated the effect of information provided by CMS on drivers' route choice. Lai and Wong (2000) examined driver comprehension of the traffic information presented on CMS. Lai and Yen (2004) examined how CMS affected driver behavior such as changing lanes, changing route, and decreasing speed.

Moreover, using laptop computers, Dudek and Ullman (2002) investigated the effect of flashing an entire message, flashing one line and alternating text on one line on drivers' comprehension and recall. Using driving simulation experiments, Wang and Cao (2005) studied the influences of CMS format and number of message lines on drivers' response time. Dudek, Schrock, Ullman, and Chrysler (2006) examined the effect of displaying CMS with dynamic features on drivers' comprehension and response time. Ullman et al. (2007) investigated the ability of motorists to capture and process information on two CMS used in sequence. Finally, Lai (2010) examined the effects of color scheme and message lines of CMS on driver performance.

Drivers' Responses to Inclement Weather

Noticeably, only very few studies examined drivers' behavior in adverse weather such as rain, snow, and fog/smoke using questionnaire surveys. For example, Kilpelainen and Summala (2007) examined the effect of adverse weather and traffic weather forecasts on drivers' behavior in Finland using a questionnaire on perceptions of weather, pre-trip acquisition of weather information, and possible changes in travel plans. The primary finding was that drivers who had acquired information had also made more changes to their travel plans. The results also showed that drivers' behavior is basically affected by the prevailing observable conditions rather than traffic weather forecasts.

Additionally, many prior research efforts investigated drivers' responses to adverse weather conditions such as reduction in visibility due to FS by observing traffic spot speeds or using driving simulators, such as Hogema and Horst (1997), Edwards (1999), Pisano and Goodwin (2004), Maze, Agarwal, and Burchett (2006), MacCarley, Ackles, and Watts (2006), and Broughton, Switzer, and Scott (2007).

Considering the aforementioned studies, clearly many studies have analyzed drivers' behavior in response to ATIS, unexpected congestion, and the impact of both radio traffic information and CMS information. Also, a number of studies have concentrated on examining the effects of adverse weather and traffic weather forecasts on drivers' behavior. However, we suggest that there remains a need to better understand drivers' behavior at different traffic and visibility conditions. Therefore, the primary objectives of this study are to gain a basic understanding of the factors affecting drivers' behavior in adverse visibility conditions, and to examine whether drivers rely on and follow warning messages displayed on CMS and/or VSL signs in different visibility and traffic conditions.

METHODS

Participants and Sampling

Prior studies such as by the Transit Cooperative Research Program (TCRP, 2006). suggested that conducting a survey using multiple approaches would achieve a good representative sample. Therefore, three different survey approaches were used to collect the participants' responses: handout, interactive, and online questionnaires. Previous studies revealed that mail-out questionnaires yielded low response rates and do not provide interaction between the interviewer and the respondent. Due to this reason and limited budget, a mail-out questionnaire was not undertaken. Also, phone interviews were not quite suitable for use because of the need to incorporate images in the survey questions.

The surveys were undertaken in fall 2009, targeting licensed drivers in Orange and Seminole counties of Central Florida. In total, 709 drivers participated in the survey. However, only 566 responses (complete or close to being complete) were used for the analysis. In this regard, 279 responses (49.3%) were collected from the handout survey, 91 (16%) through the interactive survey, and 196 (34.7%) via the Internet.

Handout questionnaires were randomly distributed among drivers in Central Florida from different age groups. Drivers were then asked to return questionnaires back once they completed them. In the interactive survey, the surveyor met a group of people at the same time and location and explained the purpose of the survey and the steps they should follow to complete the questionnaire. In this survey method, after distributing the questionnaires to the respondents, each question or picture was

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presented on a full screen using a projector (if the interview was conducted inside University of Central Florida) or using a laptop. The presentation and interaction were carefully prepared so that the questions could be clear without biasing the responses. Regarding the online survey, links (URL) for either survey type (freeway or two-lane road) were sent randomly to about 200 commuters in the Central Florida region. Also, 500 cards containing links to either survey forms were distributed in a random manner to drivers in Central Florida from different age groups. It is worth mentioning that all images used in the present survey were printed or presented in color to help participants distinguish between the different fog conditions that were investigated.

Materials

Prior studies such as that of Huang et al. (2010) revealed that most of the FS-related crashes (48.3%) occurred on four-lane roadways, followed by two-lane roads with 33.8%. Therefore, two surveys were conducted in the present study: a freeways survey and a two-lane roads survey to examine drivers' behavior in response to reduction in visibility on those types of roadways. The two survey forms are similar in all questions; both of them contained 31 questions. The only difference was in the images that were developed. Each respondent received only one of the two surveys randomly.

To properly achieve the objectives, the two survey forms were designed to gather information about drivers' demographic characteristics, familiarity with CMS and VSL signs, perception and satisfaction with CMS and VSL signs in improving safety, drivers' responses to CMS and VSL signs in four visibility conditions (very light, light, medium, and heavy fog), and at two traffic conditions: low traffic volume (no car leading ahead) and medium–high traffic volume (some vehicles are ahead). These four fog conditions refer to visibility distances of 200–250 meters (650–820 feet), 150–200 meters (490–650 feet), 60–150 meters (195–490 feet), and 60 meters or less (195 feet), respectively. Figure 1 shows a sample question from the freeway survey.

Participants were also asked to rank their possible actions when encountering a sudden reduction in visibility due to FS or HR on a freeway/two-lane road from the safest action to the most dangerous one, based on their driving experience.

A pilot test of the surveys was conducted after identifying the candidate factors that could potentially affect drivers' behavior at poor visibility conditions. After receiving feedback, the survey forms were revised. Questions that were considered ambiguous to some individuals were adjusted and more pictures were added for more clarification.

The following introduction was used at the beginning of the questionnaire form to explain the purpose of the current survey:

> Researchers at the University of Central Florida (UCF) are currently working on a project intended to reduce accidents on Florida's Highways. To help us achieve this goal, we would like to invite you to complete this survey. All answers are anonymous. There are no anticipated risks or direct benefits to you if you decide to participate. There is no penalty if you decide not to participate. You can end your participation at anytime and you do not have to answer any questions that you do not want to answer. The survey will take only about 5–10 minutes of your time.

Validating Survey Sample

To test whether the sample well represents the licensed drivers in Orange and Seminole counties, the percentages of gender and age groups of the survey sample were compared to the corresponding percentages of the licensed drivers in those two counties (January 2009) that were obtained from the Florida Department of Highway Safety and Motor Vehicles (DHSMV).

To achieve this goal, a chi-squared test for specified proportions and a large-sample test of hypothesis about a population proportion (Z-test) were estimated. The results indicated that there is no significant difference between the percentages of males and females in the survey sample and licensed drivers in Orange and Seminole Counties. A similar conclusion was found for the age groups. Hence, it was concluded that the survey sample represented the population properly in terms of age and gender of the licensed drivers in Orange and Seminole counties.

RESPONSE ANALYSIS

In total, 566 responses were used in the analysis presented in this study. The frequencies and percentages of the survey sample are summarized in Table 1. As shown in Table 1, about 55% and 45% of participants were males and females, respectively. Also, about 49% of responses were from the handout survey, 16% through the interactive survey, and 35% via the Internet. Moreover, the numbers of respondents for the freeway and the two-lane road surveys were 262 (46.3%) and 304 (53.7%), respectively.

Respondents were asked if they were previously involved in crashes due to FS or HR. According to Table 1, about 4% and 11% of the respondents reported that were involved in FS and HR crashes, respectively.

Moreover, respondents were asked if they have previously encountered CMS and VSL signs on freeways/two-lane roads. The results indicated that the majority of respondents (83.6% and 68.2%) are familiar with CMS and VSL signs, respectively.

As mentioned earlier, one of the objectives of this study is to determine the content of the message that is perceived to achieve the best safety and drivers' compliance. Considering drivers' opinions, 216 respondents (38%) stated that the best message is "Caution–fog ahead–reduce speed." By testing the homogeneity of proportions of the given messages, the hypothesis that all proportions are equal was rejected at the 5% level of significance ($\chi^2 = 274.7$, DF $= 5$, p value $< .0001$), which implies that there is significant difference in selection of messages and that the

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Figure 1 Sample questions from the freeway survey (color figure available online).

aforementioned message was selected as the best message by the larger proportion of participants. The percentages of drivers' choices for other alternative messages are listed in Table 1.

In addition, the responses revealed that the majority of respondents (83.2%) agree with the usefulness of using two successive CMS prior to FS zones for warning drivers about any sudden reduction in visibility. This could provide drivers with another chance to read the content of the warning message of the second CMS if they missed the first one.

Furthermore, drivers were asked about their satisfaction with the usefulness of using CMS and VSL signs on a 5-point scale ranging from *strongly disagree* to *strongly agree*. About 94% of respondents (who agree or strongly agree) reported that they are satisfied with the usefulness of CMS, while 76% of participants (who agree or strongly agree) stated that VSL signs could be useful in reducing the number of FS crashes (as shown in Table 1). This difference could be attributed to the fact that drivers in Florida are not familiar with VSL signs compared to CMS.

Another objective of this study was to investigate the best way to improve safety during driving through FS zones based on drivers' expectations and preferences: using CMS only, using VSL signs only, using CMS and VSL signs simultaneously, or closing the road during such adverse weather conditions. Most of the respondents (63.8%) stated that using both CMS and VSL signs together is the best way to improve safety during these adverse weather conditions (as shown in Table 1).

This result is logical because warning drivers that there is fog ahead using CMS only does not instruct them on what to do. Therefore, using VSL signs is also important to instruct drivers about the safe speed at every visibility conditions. This result is consistent with prior studies such as Perrin, Martin, and Coleman (2002). The hypothesis that the proportions of all possible ways to improve safety are equal was rejected at the 5% level of significance ($\chi^2 = 576.9$, DF = 3, p-value < 0.0001) which means that using CMS and VSL signs together during adverse visibility conditions was preferred by the larger proportion of participants.

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Table 1 Distributions of survey sample.

Variables	Categories	Number of respondents	Percentages of respondents
Gender	Male	310	54.8
	Female	256	45.2
Age groups (years)	18–25	173	30.6
	26–35	120	21.2
	36–50	136	24.0
	+51	137	24.2
Education levels	Graduate school or higher	122	21.6
	College degree	182	32.1
	Some college	188	33.2
	High school or less	74	13.1
Survey type	Handout	279	49.3
	Interactive	91	16.0
	Online	196	34.7
Road type	Freeways	262	46.3
	Two-lane roads	304	53.7
Involved in FS crashes	Yes	22	3.9
	No	544	96.1
Involved in HR crashes	Yes	61	10.8
	No	505	89.2
Drivers' familiarity with CMS	Yes	473	83.6
	No	93	16.4
Drivers' familiarity with VSL signs	Yes	386	68.2
	No	180	31.8
Drivers' opinion of the messages that will achieve the best safety and driver compliance	Fog ahead–Reduce speed	71	12.5
	Caution–Fog ahead–Reduce speed	216	38.2
	Fog ahead–Reduce speed–Fine doubled	91	16.1
	Fog ahead–Reduce speed–Strictly enforced	132	23.3
	Caution–Reduce speed–Strictly enforced	41	7.2
	Other	15	2.7
Drivers' opinion about the best way to improve safety during poor visibility conditions	Using CMS only	176	31.1
	Using VSL sign only	16	2.8
	Using CMS and VSL signs together	361	63.8
	Closing the road	13	2.3
Drivers' satisfaction with the usefulness of CMS in warning them about reduced visibility conditions	Strongly agree	268	47.4
	Agree	261	46.1
	Neither agree nor disagree	24	4.2
	Disagree	13	2.3
	Strongly disagree	0	0
Drivers' satisfaction with the usefulness of VSL sign in reducing the number of fog related crashes by informing them about safe speed limit under reduced visibility conditions	Strongly agree	187	33.0
	Agree	243	42.9
	Neither agree nor disagree	78	13.8
	Disagree	47	8.4
	Strongly disagree	11	1.9

To obtain an in-depth understanding of drivers' likely behavior in response to CMS and VSL instructions at different visibility conditions, 10 scenarios were designed for both freeways and two-lane roads (as shown in Table 2). Two scenarios include two pictures for a freeway/a two-lane road and a CMS displaying the following message: "Fog ahead—speed reduced" (as shown in Figure 2). Respondents were asked about their likely actions when driving on a freeway at a speed of 65 mph (or on a two-lane road at a speed of 45 mph) and encountering a portable CMS advising them to reduce speed due to reduction in visibility under two conditions: low traffic volumes (no car leading ahead) and medium–high traffic volumes (some vehicles are ahead).

The other eight scenarios consisted of eight pictures for a freeway/two-lane road; each picture contained a VSL sign advising drivers to reduce their speed to 40 mph in the freeway survey and to 25 mph in the two-lane road survey. Four out of these eight scenarios were designed at low traffic volume and at four fog conditions (very light, light, medium, and heavy fog), while the other four scenarios were developed at medium–high traffic volume and at the same four fog conditions (Table 2). An example of these questions is shown in Figure 1. It is worth mentioning that although using blinkers during driving is not legal in many states, many people do not know this and do it anyhow (adding this option was recommended during the pilot

Table 2 Description of scenarios.

Scenario	Sign	Visibility conditions	Traffic conditions
1	CMS	Light fog	No car leading ahead
2			Some vehicles are ahead
3	VSL	Very light fog	No car leading ahead
4		Light fog	
5		Medium fog	
6		Heavy fog	
7		Very light fog	Some vehicles are ahead
8		Light fog	
9		Medium fog	
10		Heavy fog	

survey). Also, it was decided to study drivers' responses to CMS at only one fog condition (light fog) to reduce the numbers of survey questions.

Drivers' responses to CMS and VSL signs at different fog and traffic conditions for freeway and two-lane road cases are summarized in Tables 3 and 4, respectively. Table 3 indicates that only 37% of the respondents reported that they would reduce speed immediately or reduce speed and put blinkers on when encountering a CMS that advises them to reduce speed due to reduced visibility condition, at low traffic volume while driving on a freeway. At medium–high traffic volume, this percentage increased to 51.6%. This seems reasonable because of the effect of traffic volume, as it is one of the most important factors affecting drivers' behavior.

For the two-lane road case, the percentages of drivers who were willing to reduce speed immediately or reduce speed and put blinkers on following CMS instructions at low and medium–high traffic volumes are 38.5% and 56.9%, respectively. Again, this result implies that drivers are more cautious when driving at medium–high traffic volume. Table 3 indicates that drivers are more cautious when driving on two-lane roads under adverse visibility conditions compared with driving on freeways. However, a Z-test indicated that the differences of proportions between drivers' responses when driving on freeways and on two-lane roads were not statistically significant.

As shown in Table 4, both fog and traffic conditions greatly affect drivers' stated responses to safe speed limits displayed on VSL signs at each of the aforementioned eight scenarios. As the visibility distance is reduced and traffic volume increases, drivers tend to follow VSL sign instructions. With respect to the survey made in a freeway, the percentage of respondents who said they would reduce their speed or reduce speed and put blinkers on increased from 63.4 to 77.1 to 96.6 to 98.5% for low traffic volumes and increased from 44.7 to 51.1 to 76 to 89.7% for medium–high traffic volumes. Higher values were obtained for the two-lane road survey. Again this implies that traffic volume, type of road, and visibility condition affected the likelihood of reducing the speed following VSL/CMS instructions.

Furthermore, as shown in the last column of Table 4, only 35.1% of respondents stated that they would follow VSL signs' instructions (i.e., reduce their speed to 40 mph or less) while driving on a freeway at very light fog and low traffic volume. The results also reveal that the percentages of drivers who are willing to follow VSL signs instructions increase as the visibility distance deteriorates and traffic volume increases. For example, the percentage increased to 82.1% at heavy fog and medium–high traffic volume. The same conclusion applies to two-lane roads but with higher percentages of compliance

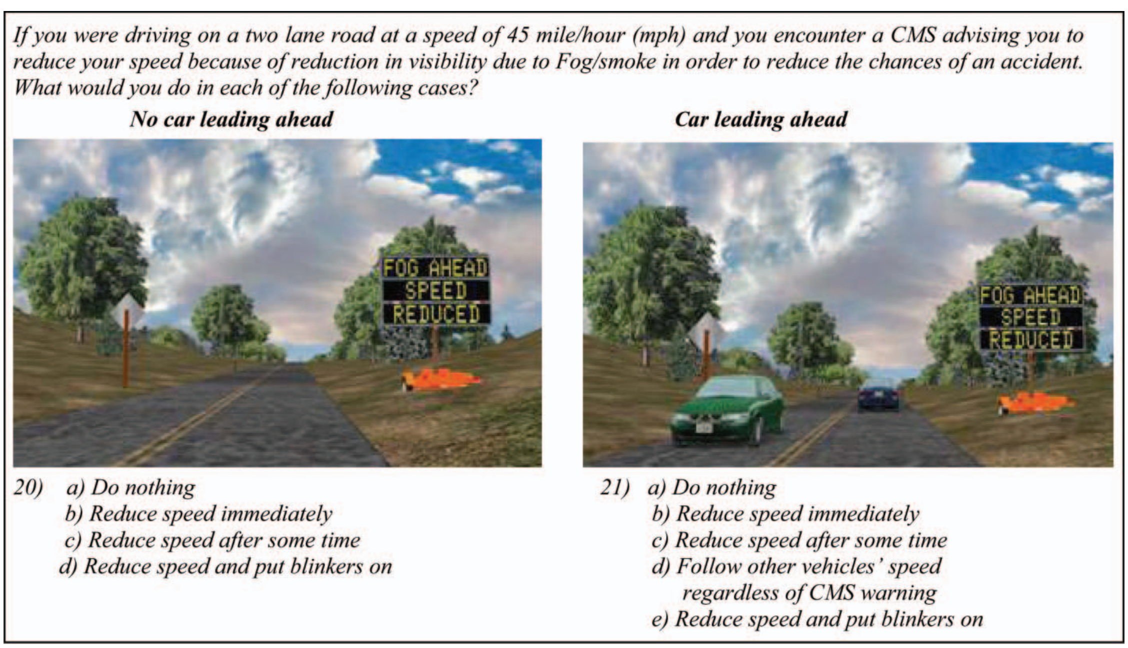

Figure 2 Sample questions from the two-lane road survey (color figure available online).

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Table 3 Summary of drivers' responses to CMS instructions.

Traffic conditions	Fog conditions	Do nothing	Reduce speed after some time	Follow other vehicles' speed	Reduce speed immediately or reduce speed and put blinkers on
Drivers' behavior for freeway survey (sample size = 262)					
Low traffic volume	Light fog	56 (21.4%)	109 (41.6%)	NA*	97 (37%)
Medium–high traffic volume		20 (7.6%)	63 (24%)	44 (16.8%)	135 (51.6%)
Drivers' behavior for two-lane road survey (sample size = 304)					
Low traffic volume	Light fog	44 (14.5%)	143 (47%)	NA*	117 (38.5%)
Medium–high traffic volume		11 (3.6%)	71 (23.4%)	49 (16.1%)	173 (56.9%)

*Not applicable.

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with VSL signs instruction. However, using *Z* and chi-squared tests, no significant differences were found between drivers' responses to VSL signs while driving on freeways versus two-lane roads or while driving at low versus medium–high traffic volumes.

Finally drivers were asked to rank the following six options from the safest action (rank 1) that they thought would minimize the chance of a FS crash, to the least safe one (rank 6): (1) do nothing, (2) drive below speed limit, (3) drive below speed limit following the instructions of VSL signs and/or CMS, if they are available, (4) follow other vehicles' speed regardless of CMS and VSL signs warnings, (5) drive below speed limit and put blinkers on, (6) abandon the journey and stop the car immediately at the right shoulder of the road.

The results revealed that 36.2% of the respondents claimed that following the instructions of CMS and VSL signs is the safest action. Driving below the speed limit and putting blinkers on came in the second place with 26.3%. On the other hand, 86% stated that doing nothing is the most dangerous action. "Abandon the journey and stop the car immediately at the right shoulder of the road" came next with about 10%. Some participants pointed out that the last option is dangerous as it might increase rear-end crashes, especially at heavy fog conditions.

Prior to the modeling process, conditional distributions, odds ratios, and chi-squared tests were used for preliminary investigation of the differences between drivers' responses to CMS and VSL signs at different traffic and visibility conditions. Table 5

Table 4 Summary of drivers' responses to VSL signs' instructions.

Traffic conditions	Fog conditions	Do nothing	Follow other vehicles' speed	Reduce speed or reduce speed and put blinkers on	Reduce speed to 40 mph or less
Drivers' behavior for freeway survey (sample size = 262)					
Low traffic volume	Very light fog	96 (36.6%)	NA*	166 (63.4%)	92 (35.1%)
	Light fog	60 (22.9%)	NA*	202 (77.1%)	104 (39.7%)
	Medium fog	9 (3.4%)	NA*	253 (96.6%)	155 (59.2)
	Heavy fog	4 (1.5%)	NA*	258 (98.5%)	201 (76.7%)
Medium–high traffic volume	Very light fog	43 (16.4%)	102 (38.9%)	117 (44.7%)	93 (35.5%)
	Light fog	22 (8.4%)	106 (40.5%)	134 (51.1%)	107 (40.8%)
	Medium fog	4 (1.5%)	59 (22.5%)	199 (76.0)	159 (60.7%)
	Heavy fog	2 (0.8%)	25 (9.5%)	235 (89.7%)	215 (82.1%)
Drivers' behavior for two-lane road survey (sample size = 304)					
Traffic conditions	**Fog conditions**	**Do nothing**	**Follow other vehicles' speed**	**Reduce speed or reduce speed and put blinkers on**	**Reduce speed to 25 mph or less**
Low traffic volume	Very light fog	110 (36.2%)	NA*	194 (63.8%)	108 (35.5%)
	Light fog	65 (21.4%)	NA*	239 (78.6%)	127 (41.8%)
	Medium fog	8 (2.6%)	NA*	296 (97.4%)	183 (60.2%)
	Heavy fog	2 (0.7%)	NA*	302 (99.3%)	242 (79.6%)
Medium–high traffic volume	Very light fog	44 (14.5%)	113 (37.2%)	147 (48.3%)	117 (38.5%)
	Light fog	24 (7.9%)	121 (39.8%)	159 (52.3%)	141 (46.4%)
	Medium fog	0 (0%)	64 (21.1%)	240 (78.9%)	196 (64.5%)
	Heavy fog	0 (0%)	25 (8.2%)	279 (91.8%)	262 (86.2%)

*Not applicable.

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Table 5 Conditional distributions and odds ratio.

Factor		Driver's response to VSL sign instructions at heavy fog and medium–high traffic volume: Do nothing or follow other vehicles' speed	Reduce speed or reduce speed and put blinkers on	Total	Odds ratio
Gender	Male	48 (80%)	262 (51.8%)	310 (54.8%)	1
	Female	12 (20%)	244 (48.2%)	256 (45.2%)	3.7
	Total	60 (100%)	506 (100%)	566 (100%)	
Age (years)	18–25	33 (55%)	140 (27.7%)	173 (30.6%)	1
	26–35	14 (23.3%)	106 (20.9%)	120 (21.2%)	1.8
	36–50	7 (11.7%)	130 (25.7%)	137 (24.2%)	4.4
	+51	6 (10%)	130 (25.7%)	136 (24%)	5.1
	Total	60 (100%)	506 (100%)	566 (100%)	
Drivers' familiarity with VSL signs	No	31 (51.7%)	149 (29.4%)	180 (31.8%)	1
	Yes	29 (48.3%)	357 (70.6%)	386 (68.2%)	2.6
	Total	60 (100%)	506 (100%)	566 (100%)	
Past experience with driving at adverse visibility conditions	No	19 (31.7%)	91 (18%)	110 (19.4%)	1
	Yes	41 (68.3%)	415 (82%)	456 (80.6%)	2.1
	Total	60 (100%)	506 (100%)	566 (100%)	
Involved in FS crashes	No	20 (90.9%)	486 (89.3%)	506 (89.4%)	1
	Yes	2 (9.1%)	58 (10.7%)	60 (10.6%)	1.2
	Total	22 (100%)	544 (100%)	566 (100%)	
Involved in HR crashes	No	55 (91.7%)	450 (88.9%)	505 (89.2%)	1
	Yes	5 (8.3%)	56 (11.1%)	61 (10.8%)	1.4
	Total	60 (100%)	506 (100%)	566 (100%)	

Factor		Driver's response to CMS instructions at medium–high traffic volume: Do nothing or reduce speed after some time or follow other vehicles' speed	Reduce speed immediately or reduce speed and put blinkers on	Total	Odds ratio
Gender	Male	162 (62.8%)	148 (48.1%)	310 (54.8%)	1
	Female	96 (37.2%)	160 (51.9%)	256 (54.8%)	1.8
	Total	258 (100%)	308 (100%)	566 (100%)	
Age (years)	18–25	119 (46.1%)	54 (17.5%)	173 (30.6%)	1
	26–35	49 (19.0%)	71 (23.1%)	120 (21.2%)	3.2
	36–50	58 (22.5%)	78 (25.3%)	136 (24.0%)	3.0
	+51	32 (12.4%)	105 (34.1%)	137 (24.2%)	7.2
	Total	258 (100%)	308 (100%)	566 (100%)	
Road type	Freeway	127 (49.2%)	135 (43.8%)	262 (46.3%)	1
	Two-lane road	131 (50.8%)	173 (56.2%)	304 (53.7%)	1.2
	Total	258 (100%)	308 (100%)	566 (100%)	
Drivers' familiarity with CMS	No	221 (85.7%)	252 (81.8%)	473 (83.6%)	1
	Yes	37 (14.3%)	56 (18.2%)	93 (16.4%)	1.3
	Total	258 (100%)	308 (100%)	566 (100%)	
Past experience with driving at adverse visibility conditions	No	211 (81.8%)	245 (79.5%)	456 (80.6%)	1
	Yes	47 (18.2%)	63 (20.5%)	110 (19.4%)	1.2
	Total	258 (100%)	308 (100%)	566 (100%)	

Note. The percentage within parentheses is cell size relative to the group total.

summarizes the results of conditional distributions and odds ratios. The odds ratios were estimated for each group with respect to the first category of that group.

Concerning the gender, the odds ratio of females implies that when driving at heavy fog and medium–high traffic volume, the odds of following VSL instructions are 3.7 times higher for females than for males. Also regarding age, the result supports the hypothesis that older respondents are more likely to respond to VSL instructions than young participants. For example, the results revealed that the likelihood of following VSL instructions is 5.1 times higher for older drivers than for younger drivers (18–25 years old).

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Regarding drivers' familiarity with VSL signs, it was found that the odds of following VSL instructions are 2.6 times greater for drivers who are familiar with VSL than for those who are not. In addition, the likelihood of following VSL instructions is 2.1 times higher for experienced drivers than for drivers who are not familiar with driving at poor visibility conditions. Similar results were obtained for drivers' response to CMS (Table 5). Concerning road type, it was found that the probability of following CMS while driving on two-lane roads is 1.2 times higher than while driving on freeways.

As expected, it was found that when driving at heavy fog and medium–high traffic volume, the odds of following VSL instructions are higher for participants who were involved in FS crashes than those who were not involved in such crashes (1.2 times higher, as shown in Table 5). Similarly, the odds of following VSL signs under heavy fog condition and medium–high traffic volume is 1.4 times higher for participants who were previously experienced HR crashes than for those who were not involved in such crashes.

A chi-squared test was developed to explore the association between drivers' responses to CMS/VSL signs and other factors such as age, gender, education, drivers' familiarity with VSL/CMS, and experience with driving at adverse visibility conditions. The results showed significant association between drivers' response to VSL/CMS and those variables.

In summary, all the preliminary test results revealed that the participants' responses to CMS and VSL instructions vary by gender, age, familiarity with CMS and VSL signs, and experience with driving at adverse visibility condition. Thus, to improve our understanding of the preferences of respondents in following VSL and CMS instructions under such adverse visibility conditions, multivariate analyses, the bivariate and multivariate probit models, were employed for further analyses.

DRIVERS' REACTION TO CMS AND VSL SIGNS

This section emphasizes two methodological approaches for analyzing drivers' responses to CMS and VSL signs at different visibility and traffic conditions, namely, bivariate probit models (BPMs) and the multivariate probit model (MPM).

MPM has been widely used in agricultural, statistical, and economic studies for analyzing potentially correlated multivariate outcomes. These studies include Gibbons and Wilcox-Gök (1998), Lansink, Berg, and Huirne (2003), Lu and Song (2006), and Young, Valdez, and Kohn (2009). In addition, MPM has been developed in few transportation-related studies such as Choo and Mokhtarian (2008) and Rentziou. Milioti, Gkritza, and Karlaftis (2010).

MPM is a generalization of the BPM used to estimate several correlated binary outcomes jointly (Ashford & Sowden, 1970). The model specification for the simultaneously estimated BPM can be explained as follows:

$$Y_1^* = \beta X_1 + \acute{\varepsilon}_1 \quad Y_1 = 1 \text{ if } Y_1^* \geq 0; 0 \text{ otherwise} \tag{1}$$

$$Y_2^* = \alpha X_2 + \acute{\varepsilon}_2 \quad Y_2 = 1 \text{ if } Y_2^* \geq 0; 0 \text{ otherwise} \tag{2}$$

where Y_1^* and Y_2^* are the estimated dependent variables; Y_1 and Y_2 are the observed choices for dependent variables; X_1, X_2 is the vector of explanatory variables influencing choice behavior; β, α are coefficient vectors; and $\acute{\varepsilon}_1$, $\acute{\varepsilon}_2$ are random error terms.

The error terms $\acute{\varepsilon}1$ and $\acute{\varepsilon}2$ are estimated according to:

$$E[\acute{\varepsilon}1/X_1, X_2] = E[\acute{\varepsilon}_1/X1, X_2] = 0 \tag{3}$$

$$\text{Var}[\acute{\varepsilon}_1/X_1, X_2] = \text{Var}[\acute{\varepsilon}2/X1, X_2] = 1 \tag{4}$$

$$\text{Cov}[\acute{\varepsilon}_1, \acute{\varepsilon}_2/X_1, X_2] = \rho \tag{5}$$

where ρ is the correlation coefficient between the two error terms. If ρ equals zero, the bivariate probit model converges to two separate binomial probit models. In addition, the model parameters of the two probit equations are estimated simultaneously using full information maximum likelihood estimation. Parameters vectors β, α, and ρ are estimated to maximize the likelihood function. Also, significant ρ will imply the presence of unobserved individual factors (heterogeneity) that affect both dependent variables used in the BPM. For detailed information regarding BPMs and MPM, the reader is referred to Meng and Schmidt (1985), Abdel-Aty et al. (1994), Mohanty (2002), and Greene (2003).

In this study, several BPM models were estimated first to identify the dependent variables that better explain drivers' responses to CMS and VSL signs under adverse visibility conditions. Then, these dependent variables were used to estimate the MPM. The advantage of using MPM is that all dependent and explanatory factors affecting drivers' responses to CMS and VSL signs at different traffic and visibility conditions can be shown and discussed in one model framework instead of explaining several BPMs separately. In addition, correlations between several equations can also be accounted for.

It is worth mentioning that Limdep package was used to estimate the models presented in this article. Three bivariate probit models were developed after investigating several alternative model formations and dependent variables (Table 6). Drivers' response to VSL signs at heavy fog and medium–high traffic volume (0 if do nothing or follow other vehicles' speed, 1 if reduce speed or reduce speed and put blinkers on) was the first dependent variable in the three models.

The second dependent variables in the three fitted BPM were drivers' response to VSL signs at very light fog and low traffic volume (0 if do nothing, 1 if reduce speed or reduce speed and put blinkers on), drivers' response to CMS at low traffic volume (0 if do nothing or reduce speed after some time, 1 if reduce speed immediately or reduce speed and put blinkers on), and drivers' response to CMS at medium–high traffic volume (0 if do nothing or reduce speed after some time or follow other vehicles' speed, 1 if reduce speed immediately or reduce speed and put blinkers on), respectively. Level 0 was considered the base case for each dependent variable.

The results of the three BPM revealed that gender, age, drivers' familiarity with VSL signs, and road type were the significant factors affecting the likelihood of reducing speed following the instructions of VSL or CMS signs in response to adverse visibility conditions. The remaining variables (such as those shown in Table 5) were tested; however, they were found to be statistically insignificant.

In addition, to improve our understanding of the factors affecting drivers' stated behavior at different visibility and traffic conditions, an MPM was developed. Based on the three BPMs mentioned earlier, it was found that the dependent variables that better explain drivers' stated response to adverse visibility conditions were drivers' response to VSL at heavy fog and medium–high traffic volume, drivers' response to VSL at very light fog and low traffic volume, and drivers' response to CMS at medium–high traffic volume. Therefore, these three dependent variables were used in the MPM.

The MPM estimates, goodness-of-fit statistics, and the correlation coefficient ρ between every two error terms in the three equations are presented in Table 7. As shown in Table 7, the coefficient of correlation ρ is statistically different from zero, illustrating the validity of using the multivariate probit framework.

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Table 6 Summary of bivariate probit models.

	First BPM model			Second BPM model			Third BPM model		
Variable description	Estimate	Standard error	*p* Value	Estimate	Standard error	*p* Value	Estimate	Standard error	*p* Value
First equation	Drivers' responses to VSL signs at heavy fog and medium–high traffic condition (Baseline: do nothing or follow other vehicles' speed)								
Intercept	0.6629	0.1290	0.0000	0.6896	0.1325	0.0000	0.6826	0.1299	0.0000
Gender—male	—[a]			—[a]			—[a]		
Gender—female	0.5889	0.1702	0.0005	0.5569	0.1748	0.0014	0.5747	0.1711	0.0008
Age (18–25)	—[a]			—[a]			—[a]		
Age (36–50)	0.6515	0.2311	0.0048	0.6219	0.2289	0.0066	0.6283	0.2232	0.0049
Age (+51)	0.6556	0.2280	0.0040	0.6036	0.2180	0.0056	0.6239	0.2186	0.0043
Drivers' familiarity with VSL signs (no)	—[a]			—[a]			—[a]		
Drivers' familiarity with VSL signs (yes)	0.5233	0.2045	0.0105	0.4807	0.2168	0.0266	0.5193	0.2075	0.0123
Road type (two–lane road)	—[a]			—[a]			—[a]		
Road type (freeway)	–0.3805	0.2077	0.0670	–0.3319	0.2141	0.1212	–0.3923	0.2175	0.0713
Second equation	Drivers' responses to VSL signs at very light fog and low traffic volumes (Baseline: do nothing)			Drivers' responses to CMS at low traffic volume (Baseline: do nothing or reduce speed after some time)			Drivers' responses to CMS at medium–high traffic volume (Baseline: do nothing or reduce or follow other vehicles' speed)		
Intercept	–0.2175	0.1032	0.0350	–1.0576	0.1241	0.0000	–0.4799	0.1149	0.0000
Gender–male	—[a]			—[a]			—[a]		
Gender–female	0.2265	0.1166	0.0520	0.2758	0.1128	0.0145	0.3346	0.1141	0.0034
Age (18–25)	—[a]			—[a]			—[a]		
Age (26–35)	0.4105	0.1468	0.0052	0.6540	0.1630	0.0001	0.6486	0.1534	0.0000
Age (36–50)	0.5372	0.1483	0.0003	0.6067	0.1588	0.0001	0.6419	0.1506	0.0000
Age (+51)	1.2097	0.1673	0.0000	1.2299	0.1589	0.0000	1.2226	0.1567	0.0000
Road type (two-lane road)							—[a]		
Road type (freeway)							–0.2973	0.1139	0.0091
Error terms correlation coefficient (ρ)	0.3534	0.0899	0.0001	0.3819	0.1149	0.0009	0.3785	0.0969	0.0001
Number of observations		566			566			566	
Log-likelihood at convergence		–499.475			–500.666			–510.442	
AIC[b]		1020.95			1023.332			1044.884	
Pseudo R-squared		0.14			0.12			0.11	

[a]Base case.
[b]Akaike information criterion.

According to the first model, when encountering a heavy fog condition with some vehicles ahead (medium–high traffic volume), female drivers are more likely than male drivers to reduce their speed or reduce their speed and put the blinkers on. This implies that female drivers are more cautious than male drivers.

Concerning age, as age increases, the likelihood of following VSL instruction at heavy fog and medium–high traffic volume increases. The results suggest that compared to younger respondents (18–25 years old), older respondents (51 years old or more) are more likely to reduce their speed following VSL instruction. This indicates that maturity and experience are essential factors that affect the driver's response to VSL instructions.

An expected finding is that drivers who are familiar with VSL signs are more likely to reduce their speed at heavy fog conditions. This could be attributed to the fact that drivers who are familiar with VSL signs and aware of their importance in avoiding a potential accident during reduced visibility due to FS are less likely to ignore their instructions.

Regarding the type of road, it was found that, at 90% confidence, the probability of reducing speed, following VSL instructions at heavy fog and medium–high traffic volume while driving on a freeway, is less than the corresponding probability while driving on a two-lane road. This suggests that drivers could be more cautious on two-lane roads.

Similar findings were obtained from the second and third equations. The second model suggests that both females and old drivers (51 years old or more) are more likely to reduce their speed following VSL instructions at very light fog and low traffic volume compared to males and young drivers (18–25 years old), respectively.

According to the third probit model, at medium–high traffic volumes and having encountering a CMS advising a

Table 7 Multivariate probit model estimates.

Variable description	Estimate	Standard error	*p* Value
First equation: drivers' responses to VSL signs at heavy fog and medium–high traffic volume (Baseline: do nothing or follow other vehicles' speed)			
Intercept	0.5690	0.1463	0.0001
Gender–male	—		
Gender–female	0.5553	0.1714	0.0012
Age (18–25)	—[a]		
Age (26–35)	0.2778	0.1712	0.1041
Age (36–50)	0.7678	0.2408	0.0014
Age (+51)	0.7637	0.2356	0.0012
Drivers' familiarity with VSL signs (no)	—[a]		
Drivers' familiarity with VSL signs (yes)	0.5001	0.2106	0.0176
Road type (2two-lane road)	—[a]		
Road type (freeway)	–0.3508	0.2193	0.1097
Second equation: drivers' responses to VSL signs at very light fog and low traffic volume (Baseline: do nothing)			
Intercept	–0.2299	0.1038	0.0267
Gender–male	—[a]		
Gender–female	0.2242	0.1174	0.0562
Age (18–25)	—[a]		
Age (26–35)	0.4501	0.1527	0.0032
Age (36–50)	0.5589	0.1496	0.0002
Age (+51)	1.2241	0.1679	0.0000
Third equation: drivers' responses to CMS at medium–high traffic volume (Baseline: do nothing or reduce speed after some time or follow other vehicles' speed)			
Intercept	–0.5007	0.1155	0.0000
Gender–male	—[a]		
Gender–female	0.3321	0.1146	0.0038
Age (18–25)	—[a]		
Age (26–35)	0.6880	0.1569	0.0000
Age (36–50)	0.6574	0.1510	0.0000
Age (+51)	1.2322	0.1571	0.0000
Road type (two-lane road)	—[a]		
Road type (freeway)	–0.2694	0.1138	0.0179
Error terms correlation coefficient between Eqs. 1 and 2 (ρ_{12})	0.3525	0.0901	0.0001
Error terms correlation coefficient between Eqs. 1 and 3 (ρ_{13})	0.3716	0.0976	0.0001
Error terms correlation coefficient between Eqs. 2 and 3 (ρ_{23})	0.2524	0.0698	0.0003
Number of observations		566	
Log-likelihood at convergence		–835.7581	
AIC[b]		1707.5162	
Pseudo R-squared		0.12	

[a]Base case.
[b]Akaike information criterion.

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reduction in speed due to poor visibility, female drivers and older drivers are more likely to reduce their speed or reduce their speed and put blinkers on than the corresponding males and younger drivers. Again, this implies that females and older drivers are more cautious than male and younger drivers, respectively.

Finally, drivers who drive on a freeway at poor visibility conditions are less likely to respond to CMS instructions than those who drive on a two-lane road. It is possible that the presence of medians on freeways could give drivers a better sense of protection from the opposing traffic and thus contribute to more cautious driving on two-lane roads.

CONCLUSIONS AND RECOMMENDATIONS

This article presented the results of a survey-based study aimed at examining drivers' response to several scenarios of visibility and traffic conditions on two types of roadways: freeways and two-lane roads. In total, 566 responses were used in the analysis. Conducting this survey using three approaches (handout, interactive, and online questionnaire) achieved a very representative sample (i.e., the sample was apparently broad and fairly uniform across age, gender, and education). No significant differences were found in the results from these three methods of data collection.

Several categorical data analysis techniques were applied to understand commuters' behavior at adverse visibility conditions. These methods included conditional distributions, odds ratio, and chi-squared tests. The results revealed that participants' stated response to CMS and VSL signs' instructions varies by gender, age, familiarity with CMS and VSL signs, past experience with driving at adverse visibility condition, and involvement in FS/HR crashes.

The findings of MPM indicated that, compared to males and younger drivers (18–25 years old), females and older drivers (51 years old or more) claim to be more likely to reduce their speed in response to CMS and VSL instructions when driving in different visibility (heavy or very light fog) and traffic conditions (low or medium–high). The results also indicated that drivers who are familiar with VSL signs claim to be more likely to follow its instructions under heavy fog conditions than those who are not. Concerning the type of road, the findings showed that the stated likelihood of reducing speed in response to CMS and VSL signs increases when driving on a two-lane road at adverse visibility condition compared to a freeway, possibly due to the absence of a median.

A further objective of this study was to investigate whether drivers would rely on and follow warning messages displayed on CMS/VSL signs at adverse visibility conditions. Only 37% of the respondents reported that they would reduce their speed immediately or reduce their speed and put blinkers on when encountering a CMS that advises them to reduce their speed due to reduced visibility condition, at low traffic volume while driving on a freeway. Also, it was found that only 35% of the respondents were willing to follow VSL instructions (reducing their speed to 40 mph or less) while driving on a freeway with very light fog and low traffic volume. Moreover, the results show that as the visibility distance deteriorates and traffic volume increases, drivers claim to be more likely to follow CMS/VSL instructions.

Based on the findings of the present study, several recommendations can be drawn as follows:

- Many respondents reported that speed limits displayed on VSL signs cannot be relied on since fog thickness is changeable every minute, and thus, the sign would not reflect the accurate safe speed limit according to the current visibility condition. This implies that accurate and real-time detection of visibility conditions is critical to the achievement of drivers' compliance. In this regard, traffic departments should make sure that speed limits and advice displayed on VSL/CMS are accurate and change according the current visibility conditions in a timely and effective way. Otherwise, many drivers may lose their trust in and exceed the speed limit (NHTSA, 2009).
- "Caution–fog ahead–reduce speed" was perceived as the warning message (selected by about 38% of respondents) that would achieve the best safety and drivers' compliance in case of reduced visibility due to fog. Since most of the CMS can display two pages of messages alternatively with each message containing three lines of up to eight characters, the best message that can easily be displayed on CMS may be "Caution–Fog–Ahead" on the first page with "Reduce–Speed" on the second page.
- Using CMS and VSL signs together was reported by about 64% of respondents as the best way to improve safety during such inclement weather conditions. This is logical because warning drivers about reduced visibility using CMS should be followed by informing them what they should do using VSL signs (the safe speed at each visibility condition). This could lead to accomplish more homogenous speeds in such adverse visibility conditions. This result is consistent with prior studies such as Perrin et al. (2002).
- The majority of respondents (83%) stated that using two successive CMS prior to FS zones could provide drivers with another chance to read the content of the second CMS if they missed the first one (i.e., if the sign was occluded by other traffic or due to poor visibility conditions). This practice is therefore recommended.
- Education or communication campaigns are recommended to enhance the awareness of drivers regarding the importance of following the warning messages displayed on both CMS and VSL signs, especially when driving in heavy fog conditions. In this regard, younger drivers (18–25 years old) should be targeted for more education and awareness regarding the importance of these signs before obtaining the full driving license, particularly in states where fog is common.
- Only a minority of drivers stated that they are likely to follow CMS and VSL advice. The figure is particularly low for

young male drivers. This indicates a need for more enforcement. Strict penalties for repeat offenders, including increased driver's license points, license suspension or revocation, and higher fines, might be considered. This could improve drivers' behavior in such adverse conditions.

To improve safety under low visibility conditions, the aforementioned recommendations should be included among human factors guidelines for road systems. They may improve drivers' behavior in reduced visibility and improve drivers' compliance with VSL/CMS instructions. This could achieve more homogeneous speeds and help to reduce accidents that may occur due to sudden onset/appearance of fog or smoke.

The shortcoming of the present study is that the stated responses may not be an accurate indication of actual responses. This would be a problem if there were a large variance between the stated responses and actual behavior. However, a number of prior studies (e.g., Loomis, 1993; West, French, Kemp, & Lander, 1993; Yannis et al., 2005) reported good agreement between self-reported responses and actual ones.

Another potential limitation of this study is the possibility of strategic bias in the responses (i.e., some participants do not reveal their true preferences when there is gained benefits from not doing so). An example of strategic bias in this study might be respondents' selection of the best warning message that does not reflect fine or enforcement warnings.

While actual values or percentages should be regarded with care (i.e., be more on the conservative side), the directions and indications of the results are probably valid. Although it might be difficult, validating self-reported questionnaires with field data could be recommended in future studies to address this concern.

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