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The Impact of Potentially Realistic Fabricated Road Sign Messages on Route Change

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ABSTRACT This article studies self-reported route change behavior of 4,706 licensed drivers in the continental U.S. through a stated preference survey when they encounter road sign messages. Respondents are asked to score their likelihood of route change and speed change on a 5-point Likert scale to three messages: (1) "Heavy Traffic Due to Accident," (2) "Road Closure Due to Police Activity," and (3) "Storm Watch, Flooding in Area Soon." We fulfill three objectives. First, we identify the relationship between the route change behavior and socioeconomic and attitudinal-related factors. Second, we explore the impact of road sign messages with different contents on route change behavior. Third, we test the association between route change and speed change behaviors. The results demonstrate that: (1) the response of participants to compromised dynamic message signs varies according to the socioeconomic standing and attitude of participants, (2) the response of participants varies under different messages, and socioeconomic and attitudinal factors impact this differentiation, and (3) the likelihood of route change is positively associated with slowing down. This means, in practice, a malicious adversary has the potential to shunt and disturb traffic by disseminating fabricated messages and engineering route choice of drivers.

INDEX TERMS Cyber-physical attacks, driver behavior, information technology, intelligent transport systems, traffic information, variable message sign.

I. INTRODUCTION

DYNAMIC Message Signs (DMS) have been successfully deployed as a manifestation of Advanced Traveler Information System (ATIS) to disseminate information on traffic speed, congestion, route change, or travel time. Although the degree of obedience to the content of DMS varies depending on the type of content [1]–[6], the characteristics of drivers [7]–[10], and the characteristics of the trip [10], [11], [12], previous research notices an impartial compliance with DMS by conducting stated preference surveys, running simulators, and experiencing a field study. This compliance benefits both transport system users and providers by meeting the objective of using existing infrastructure in a more efficient manner. A potential, however, is generated for cyber-physical attackers to destabilize the operation of a transport network.

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"That Car Makes You Look Fat," "Work is Canceled, Go Back Home," "Nobody Has Ever Loved You," "You Will Never Get to Work on Time," "Drive Drunk," and "Zombies Ahead," are a few examples of road signs altered by hackers. In April 2007, one of the earliest hacking events was coined in Boston, Massachusetts by MIT students. The cyber-physical attacks then were spread across the nation to Texas, New York, Florida, Virginia, California, North Carolina, Iowa, and New Jersey. The mission of DMS was frustrated by the fabricated messages publicized in previous events.

Adversarial attacks to cyber-physical systems have raised concerns about the security of DMS. The potential risks associated with adversarial attacks should not be ignored as fabricating the content of DMS detrimentally affects the behavior of drivers [13]. In the following, we argue that a malicious adversary has a potential to shunt and disturb traffic flow by disseminating fabricated messages and engineering route choice of drivers. The behavior of drivers, of course, varies depending upon the wording and format of fabricated content.

Existing research examines the self-reported (1) distraction and change in the speed of drivers when they come across "Work Zone Ends, Speed Limit 60 mph" fabricated message [14], (2) change in speed when they experience potentially realistic (e.g., Road Closure Due to Police Activity) and unrealistic (e.g., Zombies Ahead, Run) fabricated messages [15], and (3) distraction, change in speed, and change in route when they confront "Downtown Under Terrorist Attack" fabricated messages [16]. Current knowledge, however, is scarce on the route change response behavior of respondents to potentially realistic fabricated road sign messages with different content. This study is a natural continuation of previous research [14], [15], [16] and adds to the budding literature on drivers' response to road sign messages. We add to the existing literature by comprehending how and to what extent an adversary impacts the route change decision of drivers. We recruited 4,706 licensed drivers at the national level through Amazon Mechanical Turk. Participants filled out a Stated Preference (SP) survey to score their likelihood of route change on a 5-point Likert scale under three potentially realistic messages: (1) "Heavy Traffic Due to Accident," (2) "Road Closure Due to Police Activity," and (3) "Storm Watch, Flooding in Area Soon." This study fulfills three objectives:

- *Objective 1:* To identify the connection between the route change behavior and socioeconomic and attitudinal-related factors. We hypothesize that the route change response of participants is a function of socioeconomic and attitudinal characteristics of participants. This hypothesis has been tested and corroborated in the literature of drivers' compliance with dynamic message signs with realistic information.
- *Objective 2:* To explore the differential route change decisions between different road sign message content. We hypothesize that the response of drivers varies under different messages and socioeconomic and attitudinal factors impact this differentiation.
- *Objective 3:* To understand the association between route change and speed change. We hypothesize that the willingness of respondents to change their route under road sign messages is positively correlated with the willingness to slow down.

We, hence, accomplish three tasks in the remainder of this article. First, we present the results of a stated preference survey conducted in 10 states and the District of Columbia, where they have experienced fabricated road sign messages. We elaborate on the data collection process and represent the characteristics of the data collected from 4,706 licensed drivers in the continental U.S. Second, we develop univariate latent-based ordered probit models to understand the connection between the route change decision and socioeconomic and attitudinal-related factors in different scenarios. Third, we discuss the results of the modeling and explore the association between choice of speed and route change behavior. The article is closed by summarization of the findings and proposals for avenues of future research.

II. DATA COLLECTION AND DESCRIPTION

We designed a stated preference survey to collect: (1) socioeconomic and demographic characteristics, (2) attitudinal and driving style characteristics, (3) information on experience with compromised DMS, and (4) road change and speed change response under different messages.

Following the Institutional Review Board (IRB) approval, we conducted a pilot survey in Florida, Texas, and California to modify the questionnaire and evaluate the quality of responses. Using Amazon Mechanical Turk, we then distributed the final questionnaire in CA, FL, IA, MD, MS, NC, NJ, NY, TX, VA, and DC between November and December of 2018. Over the data collection period, we received 4,706 completed questionnaires, which was reduced to 4,302 validated responses. Our sample size accounts for roughly 0.05% of the licensed driver population in each state. Table 1 summarizes the description and basic statistics of variables used for the modeling purposes.

To reduce the gap between the demographics of the sample and the population, we measured the two-tailed test and dynamically compared the distribution of gender, age, and income-level in our sample with the population at the state-level. This made us monitor the demographics of the participants during data collection and incentivize the participation of Turkers with desirable demographics. While this added time and steps to our data collection process, it augmented the representativeness of our sample population. The following items summarize the socioeconomic characteristics of the sample comprising 4,302 validated responses.

- Females form 2,301 of our respondents, which stands for 53.5% of the sample.
- The distribution of age for 34 years old and younger, between 35 and 54 years old, and 55 years old and older is 55.3%, 35.8%, and 8.9%, respectively.
- The distribution of education level is 48% with an associate degree or lower, 37% with a bachelor's degree, and 15% with a graduate degree.
- More than half of the sample earns less than $60,000 per year and 24% of the sample earns more than $90,000 per year.
- While Caucasians shape 66% of the sample, the percentage of African Americans, Asians, Hispanic or Latinos in our sample, respectively, is 9.4%, 9%, and 9.81%.
- Self-reported driving behavior shows 23.34% of participants are "Anxious," 2.28% of participants are "Reckless and Careless," 4.39% of participants are "Angry and Hostile," and 70% of participants are "Patient and Careful" when driving.

TABLE 1. Definition and basic statistics of variables used in the analysis.

Variable	Definition	Mean	St. Dev.
Driving Experience	Respondent has 1: less than 1; 2: 1-5; 3: 6-10; 4: 11-15; 5: 16-20; 6: more than 20 years driving experience	4.25	1.52
Female	1: Female; 0: Otherwise	0.53	0.50
Young Adult	1: If respondent's age is between 18 and 24; 0: Otherwise	0.14	0.35
High School	1: If respondent has a degree below high school; 0: Otherwise	0.08	0.27
Bachelor	1: If respondent has a degree above Bachelor; 0: Otherwise	0.52	0.50
Master	1: If respondent has a degree above Master; 0: Otherwise	0.15	0.36
Asian	1: If respondent is Asian; 0: Otherwise	0.09	0.29
Black	1: If respondent is African American; 0: Otherwise	0.09	0.29
White	1: If respondent is White; 0: Otherwise	0.66	0.47
Student	1: If respondent is student; 0: Otherwise	0.06	0.24
Income	Household income of participant is 1: less than 15; 2: 15-30; 3: 30-45; 4: 45-60; 5: 60-75; 6: 75-90; 7: 90-105; 8: 105-120; 9: 120-135; 10: 135-150; 11: more than 150 thousand US Dolor	4.94	2.71
Mobility Disability	1: If respondent has a mobility disability; 0: Otherwise	0.02	0.15
Rural	1: If respondent lives in rural area; 0: Otherwise	0.13	0.34
Frequent Driving	1: If respondent drives between 16 and 20 hours per week; 0: Otherwise	0.07	0.26
DMS Familiar	Respondent's familiarity with DMS from 1: Not familiar to 5: Extremely familiar	3.96	1.02
DMS Read	Respondent's frequency of reading DMS in daily commute from 1: Never to 5: Always	4.28	0.89
DMS Use	Respondent uses DMS on congested roads from 1: Never to 5: Always	3.97	1.15
DMS Attention	Respondent's attention to DMS on a 5-point Likert scale from never to always	4.31	0.82
New Route	Choosing new routes to reach destination sooner from 1: Extremely unlikely to 5: Extremely likely	3.81	1.08
Accomplishing	Respondent accomplishes more because of technology from 1: Extremely unlikely to 5: Extremely likely	4.03	0.92
Trusting Tech	Respondent trusts technology to assist in her travel from 1: Extremely unlikely to 5: Extremely likely	4.17	0.94
Relying Tech	Relying on technology for daily trips from 1: Extremely unlikely to 5: Extremely likely	3.23	1.45
Checking Traffic	Respondent checks traffic before hitting the road o from 1: Extremely unlikely to 5: Extremely likely	3.19	1.38
Using Blinker	Respondent uses blinker when changing the lanes from 1: Extremely unlikely to 5: Extremely likely	4.64	0.73
Paying Attention	Respondent pays attention to surrounding vehicles from 1: Extremely unlikely to 5: Extremely likely	4.70	0.62
Complying	Respondent complies with traffic regulations from 1: Extremely unlikely to 5: Extremely likely	4.52	0.74
Having Good Record	Respondent has a good record of driving from 1: Extremely unlikely to 5: Extremely likely	4.46	0.81

Participants were asked to assume driving on a highway with the speed limit of 60 mph to reach downtown and score their likelihood of route change on a 5-point Likert scale under three scenarios with potentially realistic fabricated messages:

- *Scenario 1:* Encountering "Heavy Traffic Due to Accident" road sign message.
- *Scenario 2:* Encountering "Road Closure Due to Police Activity" road sign message.
- *Scenario 3:* Encountering "Storm Watch, Flooding in Area Soon" road sign message.

The reason we alert the reader to the concept of "fabricated" is our approach in collecting information. Although participants were not directly informed that the messages are fabricated, they were given information about the fabricated messages and introduced to different real-world examples in the questionnaire. This happened before they score their likelihood of route change in each scenario. We speculate that they had the possibility of fabricated road sign messages in mind when they were answering their likelihood of behavioral response. However, whether the DMS information is fabricated or not, understanding the responses of different travelers in our scenarios help information service providers deliver a better travel support.

Figure 1 depicts the likelihood distribution of behavioral response of drivers in each scenario. Regardless of the scenario, majority of respondent are "extremely likely" or "somewhat likely" to detour and slow down. Results show 64% and 67% of respondents are "extremely likely" or "somewhat likely" to change their route under Scenario 1 and Scenario 2, respectively. The likelihood of slowdown is slightly higher in each scenario. An interesting observation is that the likelihood of speed up, although it is marginal in general, is slightly higher in Scenario 3 than the other two scenarios. We speculate it is due to the context of message. It is expected that drivers speed up to avoid getting caught in a flood. Another observation is the low probability of ignoring the message in all scenarios. This means drivers, even with the knowledge of potential road sign message fabrication, are more likely to respond to the message when it disseminates a potentially realistic information. The reader is referred to [14], [15], [16] for an in-depth discussion on the descriptive of the data and behavioral responses to realistic and unrealistic fabricated road sign messages.

One limitation to our data is we did not control for all demographics, such as educational attainment and car ownership. Our sample, however, is representative of gender, age, and income-level of the population in each state. Another limitation to our data is collecting self-reported responses of participants to fabricated road sign messages through a stated preference survey. The self-reporting questionnaire was selected by the research team for two reasons. First, the self-reporting questionnaire allows for us to cover context-rich demographics and geographies, which is not practical to achieve in a driving simulation environment or a field study. Driving simulators and real-world experiences are generally limited by the number of participants. This, consequently, narrows the socioeconomic and attitudinal-related characteristics of participants. This constraint is relaxed by a stated preference survey covering a larger and context-rich

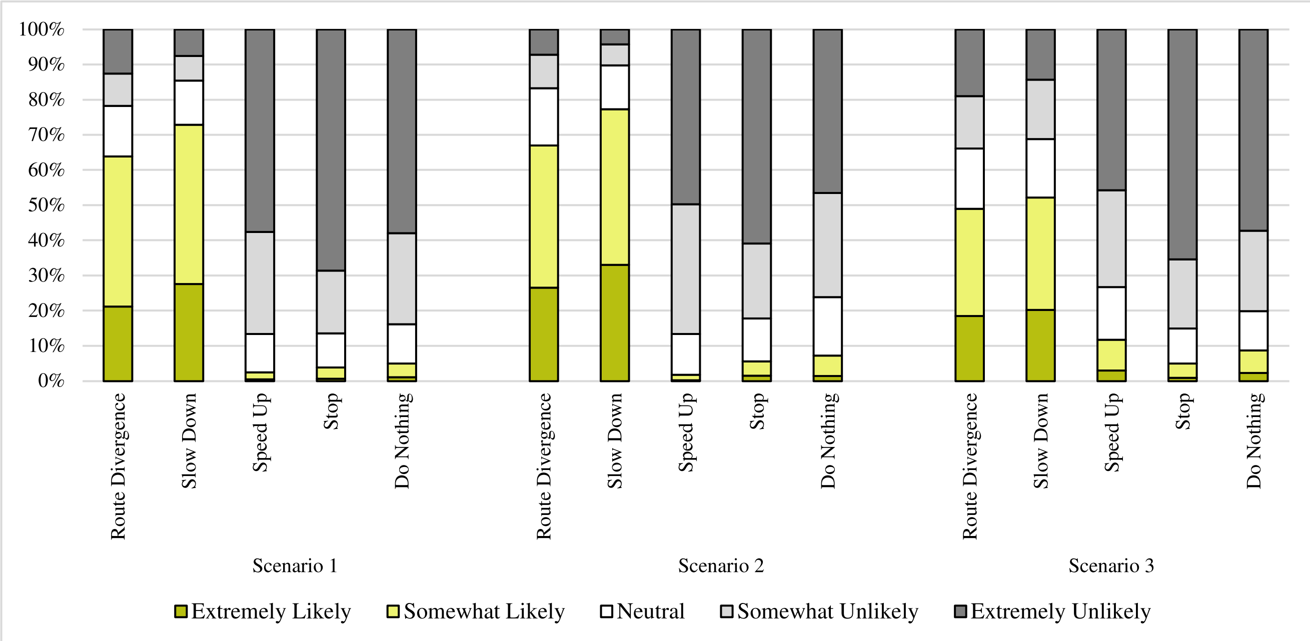

FIGURE 1. Self-reported behavioral response of 4,302 participants to road sign messages.

sample. This is particularly essential as there is no prior knowledge about the relationship between route socioeconomic and attitudinal-related factors and response to road sign messages with fabricated content. Second, aside from being a crime to fabricate road sign messages, experiencing a field study under fabricated messages is not safe. It is expected that drivers are distracted, change their speed, and change their route depending on the content of message, which might have safety consequences. We also would like to add that conducting stated preference surveys to study the compliance of drivers is a common practice [3], [17], [18] alongside running simulators [19], [20] and undertaking a field study [21], [22].

III. METHODOLOGY AND MODELING

As respondents answered to route change decision on a 1 to 5 Likert scale ranging from (1) extremely unlikely to (5) extremely likely, we develop a univariate latent-based ordered logistic regression model with the probit link function for each scenario. The utility function has the $Y_i^* = Z_i + \varepsilon_i$ form, where Z represents the observed and unobserved (latent factors) characteristic of individual n $(n = 1, 2, 3, \ldots, N)$. According to the univariate ordered-response modeling structure, the group membership of individual n, is chosen based on the threshold (cut-off point) values $(\tau_1, \tau_2, \ldots, \tau_{P-1})$. These threshold values are relative to the utility function as represented by Equation (1).

$$Y_{n,i} = \begin{cases} 1 & if\ Y_1^* < \tau_1 \\ 2 & if\ \tau_1 < Y_2^* < \tau_2 \\ \vdots & \vdots \\ P & if\ \tau_{P-1} < Y_p^*. \end{cases} \tag{1}$$

In Equation (1), P is the total number of categories of the ordered outcome variable which is equal to 5 in this study.

A. FACTOR ANALYSIS

To identify an optimum number of latent factors describing the attitude of respondents, we perform an explanatory factor analysis. We tested the factorability of 17 variables and found 11 variables describing three different factors as outlined in Table 2. The Kaiser-Meyer-Olkin Measure of sampling adequacy equals 0.758 and indicates an adequate sampling [23] while Bartlett's test of sphericity significance with a p-value lower than 0.001 indicates the suitability of detected structure. The latent variables are (1) driving habit, (2) driving attitudes, and (3) tech friendly. The main indicators of each latent variable with values greater than or equal to 0.4 are bold in Table 2.

B. MODEL RESULTS

Table 3 outlines the results of each model separately. We use McFadden's Pseudo R-Squared to assess the goodness-of-fit of the models. This measure varies between 0 and 1 and greater values indicate a better description of the model. The McFadden's Pseudo R-Square equals 0.43, 0.37, and 0.37 for Scenario 1, Scenario 2, and Scenario 3, respectively. We also judge the statistical significance of variables using Student's t-statistic and embedded variables with 90% confidence in the final models.

Out of three latent factors formed and discussed in the preceding subsection, we found Habit and Tech statistically significant. As shown in Table 3, Tech has a positive effect on route change behavior in Scenario 1 and Scenario 2. Habit has a positive effect on Scenario 3.

TABLE 2. Results of the factor analysis.

Indicators	Factors		
	Driving Habit (Habit)	Driving Attitude (Attitude)	Tech Friendly (Tech)
Paying attention to surrounding vehicles	**0.798**	-0.190	0.086
Complying with traffic regulations	**0.775**	-0.051	0.024
Using blinker when changing the lanes	**0.761**	-0.067	0.075
Having good record of driving	**0.669**	-0.204	0.037
Relying on technology for daily trips	-0.099	0.115	**0.730**
Trusting technology for travel assistance	0.203	0.130	**0.692**
Accomplishing more with technology	0.261	0.054	**0.594**
Checking traffic before hitting the road	-0.016	-0.163	**0.500**
Preferring familiar routes	0.494	**0.429**	0.083
Getting lost easily in an unfamiliar route	0.077	**0.752**	0.232
Having trouble to understand directions	-0.127	**0.714**	0.131
Taking new routes to reach destination sooner	-0.027	**-0.550**	0.350
Being up to date with news	0.273	-0.324	0.154
Getting bored by driving	-0.127	0.301	0.124
Driving the same way as the others	0.121	0.067	0.315
Trusting surrounding vehicles	-0.118	-0.086	0.200

IV. ANALYSIS OF RESULTS

Across scenarios, two findings are inferred. First, there are explanatory variables in common between scenarios, although none of the paired scenarios are explained by the exact set of explanatory variables. For instance, familiarity with DMS and driving experience are found statistically significant in Scenario 1 and Scenario 2, while level of education, ethnicity, student status, and level of income are among statistically significant variables in one of the three scenarios. Second, the explanatory variables in common between scenarios have the same sign, but the magnitude of effect varies depending on the fabricated message content.

The correlates of route change when drivers encounter "Heavy Traffic Due to Accident" are female, driving experience, education level, Asian, income level, attention to DMS, using DMS in congestion, and familiarity with DMS. The findings show the likelihood of route change is higher among female participants and participants with a high level of income and driving experience. It is also observed that familiarity with DMS, using DMS, or paying attention to the content of DMS is positively correlated with the likelihood of route change. On the contrary, low-educated drivers and Asians are less likely to detour.

The correlates of route change when drivers encounter "Road Closure Due to Police Activity" are female, driving experience, frequency of driving, familiarity with DMS, and attention to DMS. Like Scenario 1, female participants, participants with high driving experience, or participants who are familiar with DMS or pay attention to the content of DMS are more likely to change their route. The probability of route change, however, has a negative correlation with frequency of driving. Participants who drive between 16 and 20 hours per week are less likely to reroute when they experience "Road Closure Due to Police Activity".

The number of correlates of route change when drivers encounter "Storm Watch, Flooding in Area Soon" is less than other scenarios. We found a negative significant correlation between route change and four variables: (1) White drivers, (2) students, (3) rural residents, and (4) drivers with mobility disability.

We further tested the correlation between the probability of route change and our latent factors. We noticed a positive correlation between technology friendly drivers and the likelihood of detouring in Scenario 1 and Scenario 2. Drivers who "pay attention to surrounding vehicles," "comply with traffic regulations," "use blinker when change lanes," and "have good record of driving" are likely to detour in Scenario 3. We did not find a statistically significant correlation between these drivers and the likelihood of route change in Scenario 1 and Scenario 2.

As we measured correlates of compliance with DMS for fabricated messages, we found consistent and contradictory outcomes with the existing literature. We found females are more likely to comply with forged messages. This is consistent with [12], [17] but disagrees with [1], [2], [3], [7], [8], [9], [10] when drivers encounter unforged messages. In Scenario 1 and Scenario 2, we found experienced drivers are more likely to comply. This is in agreement with [4], [21] and inconsistent with [8] when drivers encounter unforged information. Previous research indicates that high-educated and high-income drivers are more responsive to DMS traffic-related information [5], [8]. We found a similar trend under the "Heavy Traffic Due to Accident" scenario.

Previous research also acknowledges that familiarity with DMS has a strong influence on the compliance of the driver. We showed drivers familiar with DMS, in general, are more likely to divert under Scenario 1 and Scenario 2. This is inconsistent with the current literature [2], [8], [10], except [4]. Finally, in agreement with [4], [24], we found a positive correlation between tech friendly drivers and the likelihood of route change.

We fulfill Objective 3 discussed in the introductory section descriptively and quantitatively. Descriptively, we represent the percentage frequency distribution of speed change and do-nothing decisions in different route divergence likelihoods in Figure 2. Quantitatively, we calculate the Pairwise

TABLE 3. Results of univariate latent-based ordered logistic regression models for route change self-reported response under different messages.

Variables	Scenario 1		Scenario 2		Scenario 3	
	Coefficient	t-test	Coefficient	t-test	Coefficient	t-test
Female	0.139	4.05	0.140	4.18	–	–
Driving Experience	0.037	3.17	0.035	3.11	–	–
Frequent Driving	–	–	-0.180	-2.85	–	–
High School	-0.147	-2.46	–	–	–	–
White	–	–	–	–	-0.182	-5.25
Asian	-0.103	-1.72	–	–	–	–
Student	–	–	–	–	-0.100	-2.45
Rural	–	–	–	–	-0.070	-2.46
Income	0.013	2.09	–	–	–	–
DMS Familiar	0.046	2.69	0.035	2.09	–	–
DMS Read	–	–	–	–	–	–
DMS Use	0.052	3.19	–	–	–	–
DMS Attention	0.119	5.26	0.199	9.59	–	–
New Route	0.075	4.75	0.056	3.56	–	–
Mobility Disability	–	–	–	–	-0.197	-1.81
Tech	0.141	3.48	0.230	5.65	–	–
Habit	–	–	–	–	0.142	4.12
Thresholds (cut-points)						
Cut 1	0.259	2.10	-0.100	-0.85	-1.023	-31.40
Cut 2	0.631	5.14	0.400	3.46	-0.559	-18.06
Cut 3	1.071	8.71	0.946	8.16	-0.116	-3.83
Cut 4	2.264	18.03	2.057	17.42	0.766	24.09
Tech						
Accomplishing	*Constant*		*Constant*		–	–
Trusting Tech	1.296	23.75	1.332	24.35	–	–
Relying Tech	1.379	20.85	1.498	20.68	–	–
Checking Traffic	0.677	12.25	0.718	12.12	–	–
Habit						
Using Blinker	–	–	–	–	*Constant*	
Paying Attention	–	–	–	–	0.941	42.02
Complying	–	–	–	–	1.015	39.25
Having Good Record	–	–	–	–	0.937	33.52
McFadden's Pseudo R-Square	0.43		0.37		0.37	

Correlation at the 95% confidence interval between the willingness of respondents to change their route under road sign messages and the willingness to slow down. Figure 2 is formed by 12 matrices and each 5 by 5 matrix represents the percentage frequency distribution of route divergence with a speed change or do-nothing decision together in each scenario. For ease of reading, the first column of the first matrix indicates the likelihood distribution of slowdown in Scenario 1 when participants reported that they are "extremely likely" to detour. As shown, 8.5%, 7.9%, 1.7%, 1.0%, and 2.0% of respondents who reported "extremely likely" for detour, respectively, are "extremely likely," "somewhat likely," "neutral," "somewhat unlikely," and "extremely unlikely" to slow down. Two results can be obtained. First, the likelihood of slowing down is higher when the likelihood of route divergence is high, regardless of the context of road sign messages. Looking at the top left-hand corner of Figure 2, it is observed that 8.5% of respondents reported that they are "extremely likely" to detour and slow down together in Scenario 1. In the same scenario, it is noticed that 49% of respondents reported that they are "extremely likely" or "somewhat likely" to detour and slow down together. Second, the likelihood of speeding up and stopping is low when the likelihood of route divergence is "extremely likely" or "somewhat likely." In Scenario 1, for example, when respondents reported that they are "extremely likely" to detour, the willingness to speed up and stop is "extremely unlikely" in 14.5% and 16.2% of cases, respectively.

Calculating the correlation between the willingness to change route and to slow down, it is noticed that the willingness to route change and to slow down are positively correlated with the correlation coefficient of 0.26, 0.30, and 0.44 under Scenario 1, Scenario 2, and Scenario 3, respectively. The results of the pairwise correlation corroborate our hypothesis that the willingness of respondents to change their route under road sign messages is positively correlated with the willingness to slow down. Comparing the correlation coefficients under different scenarios, it is also noticed

		Route Divergence Scenario 1					Route Divergence Scenario 2					Route Divergence Scenario 3				
		5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
Slow Down	5	8.5	10.8	2.7	1.4	4.2	13.5	12.5	3.7	1.7	1.6	8.6	6.3	2.6	1.0	1.6
	4	7.9	21.8	6.4	4.6	4.5	9.3	20.7	7.3	4.4	2.7	5.3	13.9	5.0	4.6	3.0
	3	1.7	5.2	3.4	1.3	1.0	1.7	4.5	3.7	1.8	0.7	1.8	4.4	5.2	2.5	2.7
	2	1.0	2.7	1.3	1.1	0.9	1.0	1.8	1.1	1.3	0.8	1.3	3.9	2.9	5.6	3.2
	1	2.0	2.3	0.6	0.6	2.1	1.0	1.0	0.5	0.3	1.5	1.3	1.9	1.3	1.2	8.6
Speed Up	5	0.2	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.8	0.9	0.3	0.3	0.7
	4	0.5	0.6	0.5	0.2	0.2	0.2	0.5	0.5	0.3	0.1	0.9	2.8	1.8	2.0	1.2
	3	1.5	4.3	3.2	1.3	0.6	2.1	4.6	2.9	1.7	0.4	1.7	4.3	4.6	2.2	2.2
	2	4.4	14.3	4.2	4.5	1.7	7.6	16.7	6.2	4.5	1.8	3.8	9.6	4.9	6.7	2.6
	1	14.5	23.4	6.5	3.1	10.1	16.6	18.6	6.7	3.0	4.9	11.3	12.9	5.5	3.7	12.3
Stop	5	0.2	0.2	0.1	0.0	0.0	0.9	0.2	0.2	0.1	0.2	0.6	0.2	0.1	0.1	0.0
	4	0.7	1.3	0.7	0.3	0.1	1.7	1.5	0.5	0.3	0.1	1.3	1.7	0.6	0.3	0.1
	3	1.4	3.9	3.2	1.0	0.3	3.3	4.9	2.8	1.0	0.2	2.0	3.4	3.3	0.9	0.4
	2	2.6	8.4	2.7	3.7	0.5	4.7	9.9	3.5	2.9	0.3	3.3	7.4	3.0	5.4	0.5
	1	16.2	28.9	7.7	4.1	11.7	15.9	24.0	9.4	5.2	6.4	11.3	17.9	10.0	8.2	18.0
Do Nothing	5	0.1	0.2	0.2	0.2	0.4	0.1	0.2	0.3	0.3	0.6	0.2	0.1	0.1	0.3	1.6
	4	0.3	1.2	0.7	0.7	1.0	0.3	1.6	1.3	1.5	1.0	0.1	0.8	1.0	1.8	2.8
	3	0.7	4.2	3.6	1.4	1.3	2.0	6.0	5.0	2.3	1.3	0.3	2.4	3.9	2.1	2.4
	2	3.2	13.2	4.0	3.8	1.8	5.6	14.6	5.0	3.3	1.3	1.8	8.0	4.6	5.9	2.5
	1	16.8	23.8	6.0	3.1	8.2	18.5	18.1	4.8	2.1	3.0	16.1	19.2	7.5	4.9	9.7

FIGURE 2. Percentage frequency distribution of speed change and do nothing of 4,302 respondents in route divergence for each scenario. 5: Extremely likely, 4: Somewhat likely, 3: Neutral, 2: Somewhat unlikely, 1: Extremely unlikely.

there is a stronger correlation between the willingness to route change and slowdown in response to messages with information irrelevant to traffic compared to traffic-related messages. We speculate that (1) drivers are more familiar with traffic-related information, and it is easier for them to respond to them, and (2) traffic-irrelevant messages have the potential to distract drivers by stimulating them to browse social media, call or text someone, or take pictures. This is supported by previous research indicating the distraction of drivers when they encounter the "Downtown Under Terrorist Attack" message, a traffic-irrelevant message [16].

V. SUMMARY AND CONCLUSION

Cybersecurity has become an emerging threat in transport operations and management systems as it relies on communications between transport providers and users. "Work is Canceled, Go Back Home," "Nobody Has Ever Loved You," "You Will Never Get to Work on Time," "Drive Drunk," and "Zombies Ahead," provide good examples of cybersecurity threats to dynamic message signs. Tampering with DMS content disrupts disseminating real-time traffic information and road conditions to travelers. The question is how travelers respond to potentially realistic fabricated road sign messages.

Depending upon the content of message, the behavioral response might fall into (1) speed change, (2) distraction, and (3) route change. We have studied the likelihood of route change in three distinct message contents: (1) "Heavy Traffic Due to Accident," (2) "Road Closure Due to Police Activity," and "Storm Watch, Flooding in Area Soon." The key findings are encapsulated in the following:

- By exploring the differential route change behavior between different bogus content, we have shown the response of drivers varies under different fabricated messages and socioeconomic and attitudinal factors impact this differentiation. "Heavy Traffic Due to Accident" and "Road Closure Due to Police Activity" showed the potential of detouring among 64% and 67% of respondents, respectively. "Storm Watch, Flooding in Area Soon" fabricated message showed the lowest impact by stimulating 49% of respondents to divert their path. In a similar study, the likelihood of route divergence was found 80% when participants imagined experiencing the "Downtown Under Terrorist Attack" content [16]. This means the content of the message has a significant impact on the route divergence decision of drivers.

- By measuring the association between route change and speed change, we have confirmed that the likelihood of route change is positively correlated with traffic slowing down. The results have indicated drivers are more likely to slow down to obey a potentially realistic fabricated message and reroute to reduce their travel time. We speculate that drivers are likely to lower their speed to react to DMS as decelerating provides time for observing and making decisions.

Our findings offer practical insights for transport researchers, operators, and managers. First, the repeated occurrence of fabricated road sign messages since 2007 in the United States means hackers are finding ways to break into road sign systems. This indicates the importance of researching the behavioral response of drivers experiencing fabricated content. As it is almost impossible to do a field study on this topic due to safety risks, running driving simulators and conducting stated preference surveys seem more reasonable. Our findings have provided a self-reported likelihood of 4,302 participants to change their route under different potentially realistic fabricated road sign messages with context-rich demographics and geographies, which is expensive to obtain by running driving simulators. This will help future researchers recruit an appropriate cohort of participants with desirable demographics when using driving simulators to collect revealed preference data. Second, we have identified that an adversary can destabilize traffic by tampering with dynamic message systems. As drivers learn to trust messages with traffic congestion, accident, and incident information to choose an efficient route, an adversary can shunt traffic deliberately by disseminating fabricated messages. This can happen to divert traffic to a particular area for executing a malicious attack. Our analysis has examined the likelihood of drivers to change their route under traffic-related and traffic-irrelevant messages and found it is more probable to detour under traffic-related messages used in our study. This difference in behavioral responses of drivers to different potentially realistic fabricated road sign messages helps information security engineers design effective firewalls sensitive to different messages and words and reduce the possibility of risky cybersecurity attacks. Third, a small percentage of drivers have experienced fabricated road sign messages. This makes our transport users more vulnerable as they have limited knowledge of responding appropriately to a malicious adversary. Our findings have indicated that female participants, participants with a high level of income, and participants with high driving experience are more vulnerable to obey potentially realistic fabricated road signs with traffic-related messages. This can be incorporated into cybersecurity education and training programs and curriculum.

Although we have discussed how drivers with a variety of backgrounds, driving styles, driving habits, and familiarity with DMS respond to fabricated messages, there is room to grow for future research.

- We collected the self-reported likelihood of participants to change their route by designing road sign message scenarios in a stated preference survey, rather than running simulation. A potential future research avenue is observing drivers' response to traffic-related and traffic-irrelevant fabricated road sign messages in a simulation-based environment. The revealed preference provides an insight on what to expect in real-life. Future research could be conducted to measure the difference between the stated preference and the revealed preference. That, however, would be prone to error as well because it would have to be conducted in a simulated environment.
- Travelers' response to DMS is related to travel purpose in many cases. We did not collect the behavioral response of travelers in different trip purposes and paid more attention to individual attributes, rather than trip attributes. Future research is called for the response behavior of travelers to DMS in different trip purpose scenarios.

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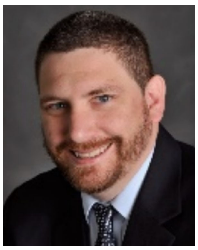

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