Abstract

This study uses a hybrid approach that incorporates a driving simulator in conjunction with a stated preference (SP) survey to analyze driver response behavior under real-time route guidance through dynamic message signs (DMS). It seeks to better understand factors affecting the route choice decisions by bridging some of the key gaps that limit the applicability of SP approaches. A large real network southwest of the Baltimore metro area is used for the driving simulator based analysis with over 100 participants. The results illustrate that past exposure to DMS, DMS information reliability, personal perceptions, and past experience are important determinants of driver response behavior in the real-world. Also, in addition to travel time, inertia and anchoring effects can significantly influence choice decisions.

Statement of Financial Interest

Validation of route choice simulators are always a major challenge in such studies. Using field data to validate drivers’ choices in simulator environment would be a great step forward. Also, integrating driving simulators (DS) with traffic simulators and taking advantages of advances in traffic flow theories would enhance the reality of DS results. Lastly, improving traffic assignment packages in transportation planning based on disaggregate route choice models is another step forward.

Statement of Innovation

This research utilized the driving simulator technique to collect route choice data under the provision of travel information on a real network with familiar and unfamiliar drivers. Study’s scenarios design and sequence assure generating extensible results.
Driving Simulator Based Analysis of Driver Compliance Behavior under Dynamic Message Sign Guidance

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ABSTRACT

This study uses a hybrid approach that incorporates a driving simulator in conjunction with a stated preference (SP) survey to analyze driver response behavior under real-time route guidance through dynamic message signs (DMS). It seeks to better understand factors affecting the route choice decisions by bridging some of the key gaps that limit the applicability of SP approaches. A large real network southwest of the Baltimore metro area is used for the driving simulator based analysis with over 100 participants. The results illustrate that past exposure to DMS, DMS information reliability, personal perceptions, and past experience are important determinants of driver response behavior in the real-world. Also, in addition to travel time, inertia and anchoring effects can significantly influence choice decisions.

Keywords: Dynamic message sign; Compliance behavior; Driving simulator.
BACKGROUND

Advanced traveler information systems (ATIS) play a significant operative role in travelers’ pre-trip route choice and en-route diversion. With the assistance of real-time traffic prediction information, ATIS guide drivers to make more informed route decisions. Dynamic message sign (DMS) is a successful and widely utilized dissemination mechanism of ATIS that can present generic information on routing to effectively manage highway congestion. Several studies evaluated the potential of DMS on route guidance and route diversion and found it to be an effective and safe traffic management device to convey real-time traffic information to drivers [1, 2, 3]. The degree of driver response to the information displayed on a DMS is a major research question that entails behavioral investigations.

Despite the extensive literature on route choice analysis in the presence of information, the ability to obtain the appropriate data has been a major challenge to the transferability of the disaggregate route choice models. Travelers’ attitudes have been elicited mostly through stated preference (SP) survey questionnaires, which do not necessarily coincide with drivers’ actual decisions. Field experiments, a more precise but costly option, are not always feasible and safe to test various traffic information scenarios and environmental conditions. A driving simulator (DS), however, supplies a more realistic environment to investigate the latent elements of route choice behavior. Transportation researchers have been using this evolving technology to investigate drivers’ route choice behavior for various controlled conditions [4, 5] and their heterogeneity in the context of developing route choice models [6].

Several studies have used the SP approach to evaluate DMS effectiveness and drivers’ compliance with travel information [7, 8, 9] and often suggested DMS ability to generate optimistic route diversion, whereby the effectiveness is strongly correlated with the quantity of information provided. A more realistic perspective toward DMS effectiveness was achieved by studies that analyzed field data in addition to SP-based analysis [10, 11]. This study utilizes DS data to analyze driver compliance behavior with DMS travel time information to better identify factors that affect drivers’ response to DMS and to provide more realistic insights on the effectiveness of DMS as a traffic management tool.

METHODOLOGY

The study utilizes the high fidelity driving simulator of UC-win/Road by FORUM8. Drivers’ socio-economic data and attitudes were also collected using pre-/post-experiment surveys. Although DMS aggregate response is crucial to DMS design, disaggregate analysis provides more insights into individuals’ understanding of and attitudes towards DMS information. One of the principle questions that can be examined at the disaggregate level is the compliance probability with the DMS guidance among individuals. Drivers are generally presumed to choose the faster route among the alternatives displayed on the DMS. The path with the shortest travel time displayed on DMS was considered as the recommended path and route choices compatible with the recommended path were counted as compliant cases.
Network Design
To ensure that travel time and distance are representative of actual driving experience, a $12 \times 12$ mi$^2$ (20×20 km$^2$) network, including real traffic and relevant roadside objects such as signs, plants, and buildings, southwest of the Baltimore (Maryland) metro area were replicated in the DS. Human subjects were asked to drive from a fixed origin—MD-100, 3.45 miles (5,550 m) west of I-95—toward downtown Baltimore. A DMS mounted on an overhead structure was embedded in the network located 1.39 miles (2,240 m) from the start point (on MD-100). The DMS provided drivers with travel time information to the destination for the two major alternatives, I-95 and MD-295, among the three existing ones. The third option is a local arterial that includes several traffic signals. I-95 is wider, shorter, and faster in normal traffic conditions, which makes it more appealing to drivers; however, it has a higher percentage of heavy vehicles.

Scenario Design
Five scenarios were developed to address various traffic regimes and travel time information. Table 1 describes the DMS’s content displayed in each scenario. The travel time difference between MD-295 and I-95 ($\Delta TT$) and the relative travel time difference are also computed in this table for each scenario. The former quantity shows the travel time savings when the alternate option (MD-295) is chosen over the reference option (I-95). Drive frequency varied from 1 to 12 times per participants with an average of 5.7 times, while the average scenario travel time was 22 minutes. The scenario sequence in response to the posterior route choices for the first four drives was planned not only to generate a fairly equal number of all scenarios randomly, but also to counterbalance the order effects. This arrangement was intended to disclose the travel time sensitivity and inertia with favorable route among the drivers.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Message</th>
<th>$\Delta TT$</th>
<th>$\Delta TT/TT_{95}$</th>
<th>Traffic Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95: 15 MIN 295:20 MIN</td>
<td>-5</td>
<td>-0.33</td>
<td>both off-peak</td>
</tr>
<tr>
<td>2</td>
<td>95: 30 MIN 295:20 MIN</td>
<td>10</td>
<td>0.33</td>
<td>95 peak</td>
</tr>
<tr>
<td>3</td>
<td>95: 30 MIN 295:30 MIN</td>
<td>0</td>
<td>0</td>
<td>both peak</td>
</tr>
<tr>
<td>4</td>
<td>95: 25 MIN 295:20 MIN</td>
<td>5</td>
<td>0.20</td>
<td>5 min hypothetical delay for 95 only</td>
</tr>
<tr>
<td>5</td>
<td>95: 35 MIN 295:20 MIN</td>
<td>15</td>
<td>0.43</td>
<td>15 min hypothetical delay for 95 only</td>
</tr>
</tbody>
</table>
Study Data
The recruitment of the study participants was conducted through flier distribution. Since participants were reimbursed for their cooperation, the variety of applicants led to a fairly unbiased sample in terms of socio-economic characteristics. Overall, 102 people completed survey questionnaires and accomplished at least one scenario, totally 577 experiments. Participants’ socio-economic (gender, age group, education level, job status, income level, household size, car ownership, and annual driving mileage) were collected through a pre-experiment survey, as well as general attitudes towards DMS (drivers’ familiarity with DMS, exposure to DMS, level of attention to DMS, usage of navigation systems, and perceptions of DMS helpfulness). Presenting a map similar to the study area, subjects’ familiarity with the network, rank-based priority of the two alternatives (I-95 and MD-295), and willingness to choose I-95 for the five DMS scenarios were obtained in another survey. The reliability of DMS information provided and perceived travel time were inquired in a post-experiment survey.

RESULTS AND DISCUSSION
Aggregate Route Choice Analysis
Figure 1 compares DS and SP (for two trip purposes of work and non-work) in the aggregate probability of choosing I-95 as a function of absolute and relative ΔTT. There are five options of ΔTT from -5 to +15; while the former boundary indicates that I-95 is 5 minutes faster, the latter boundary indicates that MD-295 is 15 minutes faster. Since the change in ΔTT was due to the change to both routes’ travel time, the relative travel time difference (attributed to I-95) was created in addition to the absolute value of ΔTT. Although all curves are descending, a subtle difference between SP and DS is identifiable. While the SP curves present a smooth systematic decline of I-95 choice probability as ΔTT and ΔTT/TT_{I-95} increase, DS curve showed a noticeable turning point from ΔTT = 0 to 5 minutes and a sharper downturn from ΔTT/ TT_{I-95} = 0 to 0.2. In the DS context, while the probability of choosing I-95 decreased only 3 percent (which was statistically insignificant at α=0.05) from ΔTT = −5 (I-95 being 5 min faster) to ΔTT = 0 (equal travel times), the choice probability decreased 30 percent when MD-295 became 5 min faster than I-95 (ΔTT = 5). This 30 percent shift was statistically significant (p-value < 0.001). Furthermore, the aggregate compliance rate with DMS information appeared to be consistently higher in the DS than in the SP for all scenarios. That is, for the four scenarios with travel time advantage, the DS resulted in higher choice probability for the shorter route.

The insignificant shift in route choice from ΔTT = −5 to 0 followed by strongly significant shift from ΔTT = 0 to 5 demonstrate inherent inertia in choosing I-95, as it is shorter, faster, and wider with higher speed limit. It shows a tendency among drivers to maintain this common dominant choice until a non-recurrent situation instantly alters this habit. This fact may not be readily identifiable in SP methods. The overall decreasing trends also suggest people were quite sensitive to DMS travel time information.
It is postulated that network familiarity and past experiences direct drivers toward the most efficient choices. The five hypothetic lines in Figure 2 illustrate that how the probability of choosing I-95 in each of the five research scenarios leads to a generally higher compliance rate with DMS guidance as subjects obtain more experience with DS. When I-95 is 5 minutes faster (the top dotted line), the choice probability ranges upward from 75 percent for the first drive to nearly 100 percent for the twelfth drive, with the increase being statistically significant. When the travel time is equal in both alternatives or MD-295 is 5 minutes faster (second and third lines from the top), a moderate ascending line exhibits the change in choice probability with drive frequency. However, none of these ascending patterns are statistically significant. Although the overall pattern in 5 minute $\Delta TT$ is not significant, this curve indicates likely effect of perceptive knowledge on route choice behavior that even five minutes saving in travel time may not impact the preferred route. For the last two scenarios (when I-95 is 10 and 15 minutes slower than MD-295), the choice probability decreased as the drive frequency increased, while only the shift associated to 10 minutes $\Delta TT$ was significant. Since these two bottom lines reached to one end probability, it can be concluded that drivers who could potentially learn from experience had already chosen the shorter path from the starting drives in the 15 minutes $\Delta TT$ scenario.

**Multi-Variate Analysis**

Since the outcome variable (DMS compliance) is binary, the logistic regression model was an appropriate mechanism to develop a compliance model. Efficiency-related attributes, driver-specific variables, and information-specific variables were the initial explanatory variables. Prior to the regression model, bi-variate correlation analysis was performed to verify the significant variables using the chi-square test. Among drivers’ characteristics, only income level appeared to be significantly correlated with DMS compliance. None of the information-specific variables (DMS exposure, DMS attention level, opinion towards DMS performance, and usage of navigation systems), actual and perceived travel times, and route familiarity were significant.

*FIGURE 1 Probability of choosing I-95 based on absolute (left) and relative (right) $\Delta TT$.*/
predictors. Drive frequency, travel time savings, and the reliability of DMS information were strongly correlated with DMS compliance.

Table 2 presents the results and goodness-of-fit of the logistic regression model using the four chosen predictors. Among them, only DMS information reliability had a close positive relationship with DMS compliance. Drive frequency had an insignificant positive relationship and income level and travel time savings had trivial negative relationships with DMS compliance. The odds of complying with DMS guidance rise nearly 60 percent as the travel time information displayed on DMS becomes more reliable. Travel time savings itself was not a strong predictor, and might be affected by other unmeasured variables such as anchoring effect and inertia. The compliance rate when I-95 is 5 minutes faster is higher than when MD-295 is even 15 minutes faster (81 percent versus 65 percent). Inertia to continue on the existing route is reciprocal to compliance behavior and both mechanisms operate simultaneously in route choice [12]. Hence, such unobservable variables can influence the regression model outcomes.

![FIGURE 2](attachment:image.png)  
**FIGURE 2** Choice probability of I-95 with drive frequency for five DMS scenarios.

**TABLE 2 Logistic Regression Model Results**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>Standard error</th>
<th>Significance</th>
<th>Exp ($\beta$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income level</td>
<td>$-0.106$</td>
<td>$0.129$</td>
<td>$0.408$</td>
<td>$0.899$</td>
</tr>
<tr>
<td>Drive frequency</td>
<td>$0.060$</td>
<td>$0.044$</td>
<td>$0.176$</td>
<td>$1.062$</td>
</tr>
<tr>
<td>$\Delta TT$</td>
<td>$-0.045$</td>
<td>$0.035$</td>
<td>$0.195$</td>
<td>$0.956$</td>
</tr>
<tr>
<td>DMS reliability</td>
<td>$0.462$</td>
<td>$0.164$</td>
<td>$0.005$</td>
<td>$1.588$</td>
</tr>
<tr>
<td>Constant</td>
<td>$-0.738$</td>
<td>$0.811$</td>
<td>$0.363$</td>
<td>$0.478$</td>
</tr>
</tbody>
</table>

Chi-square = 15.06 (0.005)  
$-2$ log likelihood = 354.19  
Nagelkerke $R^2 = 0.070$  
Percentage correct = 70.8%
CONCLUSION
In an empirical study, we collected route choice data using SP questionnaire and driving simulator (DS) techniques to evaluate the effects of driver characteristics and efficiency-related factors on compliance with DMS-based travel time information. DMS was found to be an effective tool in route choice, and the majority of drivers were responsive to the travel time information provided by the DMS and chose their routes based on guidance. When the major route became slower, the probability of choosing the alternative route became gradually higher. While SP results demonstrated a uniform behavioral pattern in compliance with DMS-based travel time information, DS results showed inertia in route choice behavior and proved that compliance is not fully correlated with DMS guidance and travel time savings. Many drivers were anchored to the study’s shorter route which was wider, faster (in normal traffic), and had a higher speed limit. Drivers expressed reluctance to change their preferred route for only 5 minutes $\Delta TT$. The compliance rate with DMS-based travel time information was 65 percent for the DS and 59 percent for the SP cases. Personal perceptions and experiences and the DMS information accuracy were important determinants in the route decisions.

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REFERENCES


