ABSTRACT
This research examined driver acceptance and behavior associated with Speed Limit and Curve Advisor systems, including influences on speed choice. Drivers experienced messages from an emulated Speed Limit and Curve Advisor system during a 2-hour public road drive. Driver tolerance for system errors and message conflicts was also studied by manipulating the accuracy of the information provided by the system. Messages were presented using either a Head-Up Display or on an in-dash Driver Information Center. Results indicate that drivers liked having speed limit information continuously available to them while driving, but the information provided by the Speed Limit Advisor did not significantly influence or alter drivers' speed choice or deceleration profiles in comparison to driving without the system. The vast majority of drivers reported that they relied on both in-vehicle and external sources of information, and incorrect information provided by the system (e.g., speed limit presented was higher than the posted speed limit) or missing speed limits (i.e., no externally posted speed limit information) did not appear to significantly influence drivers' speed choice. This was the case at transition points surrounding speed limit changes, as well as during extended periods of driving with no externally posted speed limit signs where drivers may have desired to confirm the legal speed limit. Unreliability in the system (represented by inaccurate or missing information) was found to lead to decreased trust in the system, but did not significantly change drivers' basic perception of the utility of the concept. Driving profiles related to approaching and negotiating curves were also not influenced by the presence or absence of Curve Advisor messages.

INTRODUCTION
This research examined driver acceptance and behavior associated with two in-vehicle advisory systems: a speed limit system and a curve advisory system. The Speed Advisor presents in-vehicle information relating to the external posted speed limit via a Head-Up Display (HUD) or Driver Information Center (DIC). This information is continuously available to drivers with changes in posted legal speed limits updated at the physical location of the external speed limit sign. The Curve Advisor informs drivers of the presence of a curve ahead by providing drivers with the curve direction and advisory speed in advance of curves. Both systems (Speed Limit and Curve Advisor) were functionally simulated and controlled by the experimenter (via a “Wizard of Oz” approach), allowing information updates to be “artificially” triggered and key system parameters to be manipulated, including the reliability (error rates) of the system. The primary objective of this research was to determine if a speed advisory system and/or a curve ahead advisory system is beneficial to drivers, if drivers perceive the feature to be useful, and to assess the extent to which these features influence drivers' speed choice.

METHOD
Twenty-four drivers in two age groups (30 to 40 years of age, and 55 years and older) received speed limit and curve advisor messages during the course of a 2-hour drive through public roadways in the Blacksburg, VA area. Drivers were generally unfamiliar with the route which included 32 speed limit changes and 26 curves. Drivers were not initially alerted to the presence of the Speed and Curve Advisor system or the purpose of the study, which was to understand the impact of
providing speed limit and curve information on driver performance, as well as to assess whether drivers found the information useful and beneficial. Several factors were experimentally manipulated, including the reliability of the system (90% versus 50% accuracy) and the location of the in-vehicle display (HUD versus DIC). The study used a mixed factorial design with three between-subjects and one within-subject factor, leading to a 2×2×2×2 factorial. Between-subjects independent variables included System Display Type (HUD versus DIC), System Reliability (90% correct information versus 50% correct information), and Age group (Middle versus Older). System State (On versus Off) was the only within-subject factor.

The study was performed using an instrumented 2002 Buick LeSabre equipped with a HUD mounted above the dashboard and a secondary DIC integrated above the original DIC to present speed and curve advisory system messages. The Speed Advisor provided in-vehicle information relating to the external speed limit, with changes in speed limit provided at the physical location of the external sign (no preview). Additionally, drivers who experienced the HUD were also notified if their speed exceeded the road's speed limit when the vehicle speed, which normally displayed as green, turned to amber. The Curve Advisor presented a directional curve icon in advance of the curve (Figure 1). Additionally, if available, an advisory speed replaced the speed limit information, at the physical location of the external sign. Both systems were emulated using a Wizard of Oz approach. This was accomplished by mapping the route in advance to note the location of all speed limit changes and curve segments. A computer automatically triggered the system messages at the appropriate points along the route according to the distance the vehicle had traveled (the accumulated distance was reset by the experimenter at known landmarks to account for any variance). Vehicle instrumentation captured sensor network information, video, external roadway views, and Speed and Curve Advisor system views (refer to Figure 2).

**Figure 2. Captured Video Views**

**Figure 1. Speed and Curve Advisor Messages Presented using a Head-Up Display**

**PROCEDURE**

Participants were informed that they would be evaluating several advanced vehicle features during a 2-hour drive. Once in the vehicle, participants were provided a brief orientation of the vehicle's basic controls (seat adjustments, mirrors, etc.), including features such as cruise control and OnStar. For participants in the HUD condition, the image was adjusted to be at an appropriate height for each driver (based on their preference). Testing was conducted on roads throughout the New River Valley using a defined 90-mile route selected on the basis of its relatively high frequency of speed limit changes and curves (i.e., 32 speed limit changes and 26 curves). The route included speed limit increases and decreases across a range of speeds, as well as single and multiple curves (back-to-back or a series of curves), and external sign advisory speeds.

All participants drove the same route (broken into three segments), and in the same order. The initial roadway segment, a four-lane highway with a speed limit of 55 mph, allowed participants to become comfortable with the vehicle. Drivers were exposed to the Speed and Curve Advisor system messages during the remaining two trip segments; system state (on versus off) was counterbalanced across the two route segments. During the trip, changes in speed limit messages were issued by the system as drivers approached the physical location of the external speed limit sign. Curve messages were not necessarily tied to the physical location of an external curve sign, but were provided in advance of the curve apex. In addition, the presentation of in-vehicle speed limit information was deliberately altered to provide false information at key points during the drive in order to examine the extent to which drivers would rely on the system relative to the externally posted signs - even when it was providing...
false information. In some situations the speed limit provided in-vehicle was higher than the actual posted speed limit of the road, while in others it was lower than the posted speed limit. The study also explored, more generally, how system reliability influences driver behavior. This was accomplished by exposing drivers to one of two system reliability levels: a version which was approximately 90% accurate, and a version which was approximately 50% accurate.

During each route segment, participants were asked a number of probing questions by the experimenter in order to maintain the ruse. Some of these questions were relevant to the study and pertained to the speed limit. For example, “Can you tell me the current speed limit of the road we are traveling on?” This technique allowed analysis of the participants' perception of system dependability or use by system state, display, and reliability. Participants completed a post-route questionnaire following each route segment in order to discern whether or not surrounding traffic affected how they drove during the route and to determine their awareness of external signs (if any).

RESULTS

Results suggest that drivers appreciated and desired both types of features (speed limit messages and, to a lesser extent, curve messages), but neither system significantly influenced driver speed choice or acceleration/deceleration profiles; drivers were observed to have comparable performance profiles with and without the system. Nevertheless, drivers felt that the presence of the system increased their awareness of prevailing speed limits and the presence of approaching curves.

COMPLIANCE WITH THE POSTED LEGAL SPEED LIMITS

Speed conformity measures, expressed as deviations from the posted speed limit, were used to assess how closely drivers were following the posted legal speed limits at key points during the trip as well as the relative effects of the Speed Advisor on drivers' speed choice. Figure 3 illustrates the overall mean driver speed conformity with and without the system when collapsed across all of the 12 analyzed speed segments. The chart captures driver speeds at three key locations: 1) at the physical location of the external posted speed limit sign, 2) 500 ft. following the speed limit change, and 3) 1,000 ft. following the speed limit change. The data reflected in the chart also represent the influence the system had on individual drivers, both with and without the system (within-subject). Two key observations are noteworthy. First, on average, participants tended to drive above the posted legal speed limit (above the “0” line on the chart). Secondly, although access to the system appears to increase compliance with the posted legal speed limits (particularly at 1,000 ft. following a speed limit change where the mean difference between groups is 1.75 mph), these differences are small and not statistically significant [at sign, F(1,48)= 0.03, p= 0.86; post change 500 ft., F(1,48)= 0.40, p= 0.53; post change 1,000 ft., F(1,48)= 2.47, p= 0.12]. With a single exception (driver age), no study factors were found to significantly influence driver speed conformity. Older drivers were observed to more closely comply with the speed limits than were middle-aged drivers, but this was independent of the advisor [at sign, F(1,47) = 5.87, p<.01; post change 500 ft, F(1,47) = 6.52, p<.01; post change 1,000 ft, F(1,47) = 4.55, p<.03].

Differences between baseline driving and periods of driving with the system were calculated for each individual, resulting in an overall measure of the relative amount of speed decrease or increase with the system compared to baseline driving. Data found that 62% of the drivers (15 out of 24) tended to reduce their speed with the system relative to baseline driving. The average speed reduction for these drivers was 1.86 mph. Similarly, some drivers (38%) were observed to increase their average speed over baseline driving; on average, the increase in speed was 1.52 mph. Overall, access to the system resulted in a decrease in speed of 0.14 mph relative to baseline driving. This same basic pattern of results emerged for subsequent spot speed measurements taken 500 ft. and 1,000 ft. following a change in speed limit. Thus, access to the in-vehicle Speed Limit Advisor led some drivers to decrease their speeds and others to increase their speeds relative to driving without the system, generally resulting in no significant overall net influence.

Driver Behavior (System Influence) in the Absence of Posted Speed Limit Signs

Previous analyses examined driver behavior at points surrounding changes in legal speed limits; situations in which external speed limits transitioned and signs were present. This section highlights the influence of the Speed Advisor system on driver behavior during relatively extended periods of driving without the presence of external speed limit signs; i.e., situations in which drivers may forget (or wish to
confirm) the legal speed limit. The basic issue is whether drivers come to rely on the in-vehicle information in the absence of external speed limit information, and whether the information acquired from the system influences their speed choice.

In addressing this issue, a 3-mile section of roadway was analyzed in which no speed limit information was available in the external environment. Mean driver speeds with and without access to the in-vehicle system - with no externally posted speed limit signs over this episode - show no significant differences in speeds driven. Peak speeds achieved during the 3-mile section of roadway with no externally posted speed limit signs were also examined. As illustrated in Figure 4, although access to the Speed Advisor system led to somewhat lower average maximum speeds compared to driving without the system (mean of 51.38 with the system versus 54.15 without the system), these differences were not statistically significant [F(1,23)= 3.68, \( p = .07 \)].

![Figure 4. Average Maximum Speeds With and Without the System](image)

Influence of False Speed Information
The presentation of in-vehicle speed limit information was deliberately altered to provide false information at key points during the drive in order to examine the extent to which drivers would rely on the system relative to the externally posted signs - even when it was providing false information. In some situations the speed limit provided in-vehicle was higher than the actual posted speed limit of the road, while in others it was lower than the posted speed limit. One key situation tested included two parallel roadways: a 55 mph freeway adjacent to a lower speed (35 mph) access road. Participants in the study were driving on the freeway (55 mph speed limit); however, the in-vehicle system presented the speed limit of the adjacent roadway (35 mph), mimicking a situation where the system confused the actual location of the vehicle. Speed limit signs for both roadways were visible to drivers during this episode. Data under these conditions showed no statistically significant differences in speed profiles. Some drivers openly commented about the 35 mph speed limit message, and assumed that the system must be providing erroneous information.

At another point during the drive, the in-vehicle speed limit information presented to drivers (45 mph) was higher than the externally posted speed limit of 25 mph. The posted speed limit sign was visible to drivers, although it may not have been very conspicuous and was presented shortly after turning onto the roadway. Driver speed profiles with and without the system were not statistically different.

Influence of System Reliability on Driver Behavior
The previous section illustrated driver speed choice in response to specific situations where the in-vehicle information presented to drivers was in conflict with the actual speed limit information provided by roadway signs. This section explores, more generally, how system reliability influences driver behavior. This was accomplished by exposing drivers to one of two systems, each varying in their level of information accuracy: a 90% accuracy rate, and a 50% accuracy rate. Results suggest that system reliability did not significantly influence driver speed choice; drivers whose system provided inaccurate speed information most of the time were no more or less influenced than their counterparts whose system provided predominantly accurate information. More specifically, both groups of drivers tended to conform to the posted speed limits to the same extent regardless of the reliability of the system.

CURVE ADVISOR SYSTEM
Driver speed profiles were recorded and analyzed at key points when approaching and negotiating curve segments along the test route, including 500 ft. in advance of a curve, when first entering the curve, and at the apex of the curve. Detailed analyses were performed on nine curve segments. Figure 5 depicts the overall mean driver speed conformity (degree to which drivers were complying with the posted legal speed limits) across all curve segments at these key points for situations with and without access to the Curve Advisor system (within-subject). As the figure indicates, access to the system did not influence approach speeds or speeds through the curve segments. On average, drivers were traveling at the legal posted speed limit in advance of the curve, decelerated to approximately 2 mph below the posted speed limit at the entry to the curve, and continued to decelerate to an average of 4 mph below the posted speed limit at the apex of the curve.
Results also found that driver acceleration profiles were not substantially altered or changed when driving with the Curve Advisor system. The distributions of maximum deceleration values were similar under both baseline driving (without the system) and episodes with the system; peak deceleration values in both cases were under 0.2 g's. As shown in Figure 6, maximum lateral accelerations for both situations (with and without the system) were also comparable across the two conditions. Driver lane position when approaching and negotiating curves was also measured and the number of lane deviations was examined. Approximately one-third of drivers were observed to have one or more lane deviations while negotiating the curve segments along the route. However, the occurrence of lane deviations was similar for both drivers with and without the system, suggesting that curve and speed messages were not influencing their driving performance surrounding curve segments.

Objective data support that drivers with access to the Speed Advisor system were more aware of the posted legal speed limits than were their counterparts without access to the system. The timing of the advisories was also perceived by most drivers as acceptable and generally appropriate. Unreliability in the system was shown to lead to decreased trust in the system, but drivers were still accepting of the concept. Drivers reported relying on both external road signs as well as in-vehicle messages, and drivers were able to readily identify message conflicts or spurious information provided by the system. Presentation of incorrect speed limit information or lack of system information did not significantly influence or alter driver behavior. For example, even when an external speed limit sign was not readily visible, drivers were not observed to appreciably increase their speeds based on the in-vehicle message which indicated a higher speed limit than the actual limit. The only factor in this study that was found to influence speed choice was age; on average, younger drivers tended to drive faster than older drivers. The following highlights additional key study results:

- Driving with the Speed Advisor system generally paralleled performance without the system. This applies to points surrounding changes in legal speed limits as well as extended intervals without externally posted speed limit signs.

- Access to the Curve Advisor system did not influence approach speeds or speeds through the curve segments, including longitudinal and lateral acceleration profiles or frequency of lane deviations.

- Drivers generally reported using the information provided by the system as a supplement to existing roadside signs, with 63% of drivers reporting that they were relying on a combination of the external signs and the in-vehicle system messages.

- Messages presented on the Head-Up Display (HUD) were perceived by drivers to be more readily noticeable than those presented on the vehicle's Driver Information Center (DIC) which was located low on the dash. Drivers in the HUD

**SUMMARY/CONCLUSIONS**

This research assessed driver acceptance of Speed Limit and Curve Advisor systems, and identified impacts on driver performance and behavior associated with both systems, including influences on speed choice. Drivers, who weren't initially alerted to the presence of the Advisor system nor the purpose of the study, experienced emulated Speed Limit and Curve Advisory messages during a 2-hour drive through a designated route across local area roadways in the greater Blacksburg, VA area. Driver tolerance for system errors and message conflicts was also studied by manipulating the accuracy of the information provided by the system. Messages were presented using either a HUD or on an in-dash DIC.
condition tended to notice the presence of the system much sooner than those in the DIC condition.

• The vast majority of drivers (84%) found the speed limit information provided by the system to be useful. Curve information was also perceived to be useful by many drivers, but to a lesser extent than the speed information (50% of drivers indicated that they found the curve information to be useful). Overall, nearly three-quarters of the drivers who experienced the system (71%) indicated that they would like to have this type of system in their next vehicle.

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