Drivers' Knowledge of and Preferences for Connected and Automated Vehicles

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Connected and automated vehicles (CAVs) offer many potential advantages, including improved traffic flow, reduction of traffic accidents, and increased freedom for adolescents and adults with restricted mobility. However, successful implementation of CAVs depends on several factors, especially acceptance and preferences by people. Specifically, during the earlier stage of deployment, CAVs will have to share the roads with human-driven vehicles (HDVs), which requires communication between CAVs and HDVs regarding their intentions and future actions. Therefore, as a first step in our research program, we conducted a survey of 182 U.S. drivers to assess their knowledge of CAVs and their thoughts about implementation. We report the survey results, accompanied by our interpretations.

INTRODUCTION

Connected and automated vehicles (CAVs), also known as connected and autonomous vehicles and driverless vehicles, have the potential to yield several major benefits (Edwards et al., 2021). They have the capability to (a) improve traffic flow and fuel efficiency of the transportation system compared to human-driven vehicles (HDVs), (b) increase traffic safety by reducing or eliminating the role of the human driving errors, and (c) provide transportation for older adults and other individuals who do not qualify for a driver's license. For these benefits to be realized, not only technical issues but also human factors issues must be resolved (Hancock et al., 2020). Widely recognized factors include establishing the acceptance and trust of occupants (Kaur & Rampersad, 2018), keeping the human in the loop so that a sufficient level of situational awareness is maintained (Endsley, 2018), and presenting warnings in ways that maximize quick and appropriate response by the human (Souders et al., 2020).

Less consideration has been given to the fact that, initially, CAVs and HDVs will have to share the same roadways (Chen et al., 2020). Consequently, communication among them and coordination of their actions are of paramount importance (Amirgholy et al., 2020). Much of that may come from technology in the automated vehicle, as well as from the drivers of HDVs acting in an expected manner (Rahman et al., 2021; Strange et al., 2022).

An essential step in deployment of CAVs is to understand drivers' knowledge about CAVs and attitudes toward them. Consequently, we conducted a survey of drivers to assess their knowledge of CAVs, possible interactions with them and HDVs at specific types of intersections, and opinions about implementation of CAVs on roadways with HDVs.

METHOD

The study was approved by the Purdue University Institutional Review Board prior to data collection (IRB-2021-1118). Participants were recruited from the Amazon Mechanical Turk (MTurk) platform. The recruitment criteria were: (a) living in the U.S.; (b) at least 18 years of age; (c) having a U.S. driver's license; and (d) a minimum historical approval rating of 97% (provided by the MTurk platform). The survey consisted of six sections that contained a total of 37 survey questions and one attention-check question, with some questions being conditional on the answers to prior related questions. The sections and the number of questions in each were: (a) demographics (7 questions); (b) knowledge of connected and automated vehicles (10 questions); (c) interactions with CAVs at four-way stop intersections (6 questions); (d) interactions with CAVs at roundabout intersections (4 questions); (e) interactions with CAVs when merging onto a crowded highway (6 questions); (f) final thoughts about driverless vehicles on the roads (4 questions). At the end of the survey, an optional question asking for final thoughts on ensuring safety and acceptance of driverless vehicles and a link to a debriefing document were included.

The procedure was as follows. After reading the instructions and agreeing to participate on the MTurk page, participants were redirected to the Qualtrics survey platform. On that page, they had to agree with an electronic consent form to proceed. Immediately after, the survey was presented on several pages, for which the participant clicked a computer mouse on a box at the bottom of each page to move to the next one. Once initiated, the survey took a mean of 8.7 minutes to complete, for which each participant was paid $2.00 (USD).

Two mechanisms were implemented in the survey to determine whether participants were paying attention and providing valid responses. The first was a pair of attention check questions in the Demographics section and in section 3: Interactions with Vehicles at Four-way Stop Intersections. The first question was: "How many years have you been driving?" The second question asked: "How old were you when you obtained your first driver's license?" Using each participant's age, provided in the Demographics section, two values of how long a participant had been driving were calculated. Because the values calculated with this method will be influenced by the participant's birthday and the date on which they took the survey, we used a criterion that this attention check was passed if the difference between the two calculated values was less than three years.

Another mechanism to ensure validity was to use the mouse event listener to calculate the number of clicks performed by the participant on each page. If the number of mouse clicks is less than the number of questions on that page, this difference suggests that the participant was using an automatic tool to fill in the responses. Thus, we also eliminated participants on the basis of this criterion.

RESULTS

In total, there were 252 participants who answered the survey. After applying the two criteria described in the Method section, 182 valid respondents remained. Below we summarize and present the survey results for each section.

Demographics

The first demographic question was age of the respondent, for which the mean was 37 years (*SD* = 10.7), with the range being 20-71 years. A total of 120 were male (57%) and 61 female (34%), with one preferring not to say. More than 75% specified that their education level was beyond a high school degree or equivalent (43; 24%): 20 (11%) associate's degrees, 93 (51%) bachelor's degrees, 23 (13%) master's degrees, and 2 (1%) Ph.D. degrees.

For driving-related questions, the mean driving years was 19.4 (*SD* = 10.7), minimum of 3 and maximum of 57. The estimated miles driven in a typical year showed relatively consistent percentages across the three lower ranges: 47 (26%) for 0 to 5,000 miles, 71 (39%) for 5,000 to 10,000 miles, and 48 (26%) for 10,000 to 15,000 miles. Only 16 (9%) persons indicated that they drove more than 15,000 miles/year. Most participants stated that they live in an urban (64; 35%) or suburban (82; 45%) area, with only 36 (20%) indicating rural area. For the question, "How would you characterize your willingness to engage in risky actions?", there was a tendency for more participants to respond that they were unlikely to do so rather than likely: Extremely unlikely (23; 13%), moderately unlikely (67; 37%), not sure (24; 13%), moderately likely (56; 31%), and extremely likely (12; 7%).

Knowledge of CAVS

The knowledge section began by stating, "Connected and automated vehicles (CAVs) is a name for driverless vehicles…", the latter term of which was used in the section's 10 questions since it is more commonly used in general public. Those questions queried respondents' knowledge of driverless vehicles, experiences that they may have had with them, and their thoughts regarding their presence on the roadway with HDVs. More than 98% of the participants indicated that they were aware of the implementation of driverless vehicles. Of those 179 persons, 112 (63%) responded "yes" and they were aware of reports of fatal accidents involving such vehicles, with the remainder responding "no". Although most drivers indicated that they were aware of driverless vehicles, the majority rated their level of knowledge as low or intermediate: very little (*N* = 11; 6%); little (*N* = 68; 38%); intermediate (*N* = 79; 44%); much (*N* = 19; 11%); and very much (*N* = 2; 1%). More than three times as many people answered they had little knowledge than much knowledge.

Nearly 94% of persons who answered anything other than "very little" were asked to select sources from which they acquired the knowledge. The results (see Figure 1) showed that online media (92%) and newspaper and television (67%) were the most frequent answers, with person-to-person communication (33%) being larger than the more formal reading modes of academic articles (15.5%) and popular books (9%). These answers indicate that most of the knowledge is being obtained via the popular media.

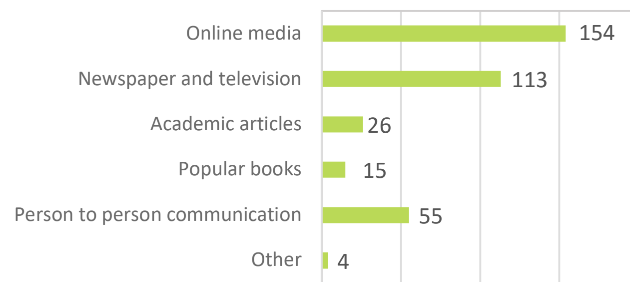

Figure 1. *Answers to "Please specify how you acquired that knowledge and describe what you know (check all that apply)."*

All participants were asked specifically whether they had heard of the concept of connected vehicles, since that concept is distinct from "automated." Less than half (*N* = 83; 46%) answered "yes". Of those who did, the knowledge ratings for connected vehicles were: very little (*N* = 166; 19%); little (*N* = 28; 34%); intermediate (*N* = 26; 31%), much (*N* = 9; 11%), and very much (*N* = 4; 5%). For those who indicated at least some knowledge, the sources were similar to those for driverless vehicles: Online media (*N* = 62; 93%) and newspaper/ television (*N* = 44; 66%) predominated, with the remaining sources being person-to-person communication (*N* = 14; 21%), academic articles (*N* = 17; 25%) and popular books (*N* = 10; 15%).

"Very little" accounted for a larger percentage of the responses to the question about knowledge of connected vehicles than to the corresponding questions for driverless vehicles (19% vs. 6%). Note that the 54% who answered "no" knowledge did not receive this question. When those persons are considered, the sum of those answering no or very little knowledge is 99 (63%) of the total respondents. So, most persons had little knowledge of the concept of connected vehicles even though almost all specified that they were aware and had knowledge of driverless vehicles.

The final questions began with indication of agreement or disagreement with the statement of "Driverless vehicles can safely share the same roadways with human-driven vehicles." Results are shown in Figure 2, for which 63% of the responses were agree or strongly agree. This was followed by a question that was different for those who indicated disagreement and those who indicated agreement. Only 5% of persons answered strongly disagree and 10% disagree (see Figure 2). For the reason of disagreement, lack of trust in driverless vehicles and artificial intelligence (AI) predominated (see Table 1). For those who agreed, the dominant reason for agreement was trust that the driverless vehicles (and AI) will have the ability to prevent accidents, but human drivers and roadway design were also specified by more than half of the participants (see Table 2).

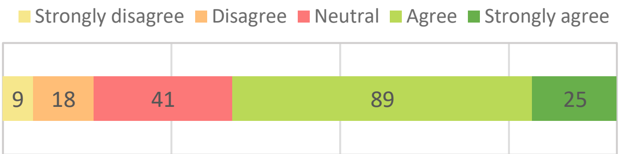

Figure 2. *Answers to "Do you agree or disagree with the following statement: Driverless vehicles can safely share the same roadways with human-driven vehicles?"*

Table 1. *Answers to the question, "What is the reason for your disagreement (check all that apply)?"*

Answer	%	Count
I do not trust the ability of driverless vehicles to prevent accidents	89%	24
I do not trust human drivers to coordinate their actions with those of the driverless vehicles	41%	11
I do not think that the roadways can be designed to accommodate both human-driven and driverless vehicles.	26%	7
I do not think that artificial intelligence can handle complicated traffic conditions	81%	22
No specific reason other than I don't think it is possible	0%	0
Total	**100%**	**27**

Table 2. *Answers to the question "What is the reason for your agreement (check all that apply)?"*

Answer	%	Count
I trust that the driverless vehicles will have the ability to prevent accidents	82%	93
I believe that human drivers will gradually get used to coordinating their actions with those of the driverless vehicles	53%	60
I think that the roadways can be designed to accommodate both human-driven and driverless vehicles.	60%	68
I think that artificial intelligence can handle complicated traffic conditions	62%	71
No specific reason other than I think it is possible	1%	1
Total	**100%**	**114**

Interactions with Vehicles at Four-way Stop Intersections

Six questions referred to 4-way stop intersections, in which traffic from all directions are to come to a stop, with one vehicle at a time proceeding through the intersection. When asked what they usually do when encountering an HDV at a 4-way stop, 158 (87%) responded "follow typical traffic protocols." Of the remaining, 19 (10%) indicated signal my intent, and 5 answered "wait for the other driver to signal me. There was more variability in the answers about how they would signal intent to proceed or wait. A total of 99 (54%) specified use of left- and right-turn signals and 49 (27%) claimed use of hand signals. The two motion-related answers, gradual initiation of vehicle motion and stopping slightly before or after the other vehicle, received 22 (12%) and 12 (7%) responses, respectively.

To the question, "How safe would you feel if one or more of the vehicles at the intersection was driverless, the answers grouped in the three intermediate categories: Very unsafe (N = 7; 4%), moderately unsafe (N = 45; 25%), neither safe nor unsafe (N = 55; 30%), moderately safe (N = 53; 29%), very safe (N = 22; 12%). For how they would signal to the driver-less vehicle, use of turn signals (N = 98; 54%) again pre-dominated, but hand signals (N = 17; 9%) decreased relative to signaling other drivers. In contrast, gradual initiation of vehicle motion (N = 43; 24%) and stopping slightly before or after the other vehicle (N = 23; 13%) increased.

As for preference regarding how a driverless vehicle would signal an intent to proceed, 99 (71%) favored visual signals from the driverless vehicle and only 9 (6%) expressed a preference for a signal inside the vehicle they were driving. Action of the vehicle was favored by 31 (22%) of the participants, and, most informative, no one specified a preference for verbal light signals on the CAV. When asked how they would feel about interacting with driverless vehicles if the stop signs were replaced with traffic signals, there was basically a shift of about 20% toward the "safe" end of the 5-alternative scale: very unsafe (N = 7; 4%), moderately unsafe (N = 25; 14%), neither safe nor unsafe (N = 42; 23%), moderately safe (N = 66; 36%), and very safe (N = 42; 23%).

Interactions with Vehicles at Roundabout Intersections

Four questions referred to a roundabout intersection, in which vehicles approaching the roundabout should yield vehicles traveling in the roundabout. To the question of how they would feel if, when entering a roundabout, they saw a driverless vehicle approaching their entrance, 57% said "safe" (N = 79; 43%) or "very safe" (N = 26; 14%). A total of 41 (22.5%) responded neutrally, whereas 27 (14.5%) indicated moderately safe and only 9 (4.9%) indicated very unsafe. For signaling intent to enter the roundabout, the values were similar to the 4-way stop, with use of vehicle lights (N = 105; 58%) predominating, gradual motion (N = 60; 33%) being second, and hand signals receiving only 15 (8%) responses.

With regard to how the driverless vehicle should signal its intent, again the preference was for use of vehicle lights (N = 82; 63%), with vehicle action second (N = 39; 30%), signals inside the driver's vehicle third (N = 8; 6%), and no responses for visual signals in words. Putting traffic lights at each possible entry to the roundabout to indicate that it is safe to enter led to a greater percentage of responses toward the safe end of the scale, but the difference apparently was not as large as for 4-way stops: very unsafe (N = 8; 4%), moderately unsafe (N = 13; 7%), neither safe nor unsafe (N = 47; 26%), moderately safe (N = 69; 38%), and very safe (N = 45; 25%).

Interactions with Vehicles when Merging onto a Crowded Highway

The final questions about a specific scenario were related to merging onto a crowded highway from a ramp. For what drivers usually do when arriving at a merging area at the same time as a vehicle on the adjacent lane, use of turn signal received the largest number of answers (*N* = 68; 37%), but not nearly as many as for the 4-way intersection and roundabout. Speeding up (*N* = 54; 30%) or slowing down (*N* = 31; 17%) together received a larger number of responses than signaling (*N* = 85; 47%). The remaining responses were: follow the merging sequence (e.g., alternately between ramp and main lane) 20 (11%) and wait for the other driver to yield (e.g., slow down or change lane) 7 (4%).

With regard to how safe they would feel if the other vehicle was driverless, only 9 (5%) and 37 (20%) answered very unsafe or moderately unsafe. This is in contrast to the values of 22 (12%) and 72 (40%) who answered very safe or moderately safe, with the remaining 42 (23%) being neutral. For preferred signaling of intent by the driver, use of left-turn signal (*N* = 118; 65%) again predominated, with vehicle speed favored by 63 (35%). The preferred way for the driverless vehicle to indicate intent to merge was also visual signals (*N* = 85; 47%). Use of visual words (*N* = 26; 14%) received some approvals, but not as many as vehicle speed (*N* = 44; 24%), with changing lanes and signals inside the driver's vehicle each receiving less than 10% of the choices. Use of a ramp meter signal again increased the safety ratings for merging with driverless vehicles: very unsafe (*N* = 8; 4%); moderately unsafe (*N* = 25; 14%); neither safe/unsafe (*N* = 30; 16.5%); moderately safe (*N* = 80; 44%); very safe (*N* = 39; 21%).

The final question in this section requested participants to rank the four types of traffic scenes targeted in the survey in terms of safety, with 1 being highest and 4 lowest. Not too surprisingly, the signalized intersection received the highest safety rating, with 98 (55%) rankings of 1. The four-way stop intersection received relatively similar rankings across the four categories, although 115 (60%) were 1 or 2. The roundabout and merging traffic scenarios received the lowest rankings, with the frequency of 4 rankings for the merging scenario (90; 53%) being twice that for the roundabout, for which the most frequent ranking was 3 (72; 41%).

Final thoughts about Driverless Vehicles on the Roads

The last questions asked for final thoughts about driver-less vehicles. For what drivers would need in order to accept driverless vehicles, likely alternatives based on the literature were provided, along with an "other" option. All alternatives received many entries (see Table 3), with demonstrated safety, clear signaling or guidance, and clear markings receiving the most. The lowest values were separation of driverless and human-driven vehicles and availability of instructions for interacting with driverless vehicles. Although these values are not negligible, they indicate that separate roadways and special instructions are not major concerns of drivers.

As might be surmised from answers to prior questions, for the question about the received sensory modality for signals from the driverless vehicles, respondents indicated a strong preference for vision (*N* = 156; 86%) over audition (*N* = 22; 12%) and tactile (*N* = 4; 2%). Coupled with the lack of desire for verbal word signals, this response implies that signaling can be achieved through customary visual signals.

Table 3. *Answers to the question "What would be needed for you to accept driverless vehicles on the roads (check all that apply)?"*

Answer	%	Count
Roadways designed with infrastructure to control interactions with human-driven vehicles	51%	93
Separation of driverless and human-driven vehicle traffic	31%	56
Demonstrated safety of mixing driverless and human-driven vehicles	73%	132
Clear markings that the vehicle is a driverless vehicle	55%	100
Clear signaling or guidance	59%	108
Availability of instructions for how to interact with the driverless vehicles	32%	58
Other	2%	4
Total	**100%**	**182**

A follow-up, open-ended question was then asked: "Why do you prefer the sensory modality you indicated in the prior question?" Due to an error in Qualtrics initially, only 170 responses were collected for this question. Following typical procedures for coding open-ended answers, the authors conducted an initial reading of the answers and established a codebook that categorized the rationales for selecting the particular modality. Two undergraduate students then studied the codebook and assigned codes for each response, after which they reviewed and compared each other's results. Finally, one of the authors played the role of moderator to resolve any disagreements and made the final decisions on the coding results. The description of codebook can be found at (https://osf.io/p2waf/?view_only=0053a9cc820948fb8298711b25e40c26).

Of the 170 answers, 146 were for persons who provided "Vision" as the preferred sensory modality to receive signals regarding driverless vehicles (86% of responses). Familiarity (*N* = 60; 41%) and Convenience (*N* = 50; 34%) were the most common reasons given for the preference. Also, 26% of respondents (45) provided more than one reason.

The penultimate question in the section was, "Do you think that the information about driverless vehicles should be signaled within your vehicle or outside by the roadway infrastructure (lights, verbal signs, etc.)?" The answer frequencies were within vehicle (*N* = 43; 24%); by infrastructure (*N* = 36; 20%), and both (*N* = 103; 57%), showing a preference for multiple sources.

The final question was "Please provide any final thoughts you may have about how to ensure safety and acceptance of driverless vehicles as they are introduced to the roadways." The answers were coded following the same analysis process as described before. This question was not answered by 62 persons, and of those who answered it, only 55 provided responses judged to be pertinent. A few answers received multiple codes, making a total of 68 answer codes. The most prevalent answers were "Better technology (e.g., AI, advanced machine design)" and "Human drivers do better (e.g., better awareness, better driving training)", with frequencies of 19 and 18, respectively. The remaining categories had fewer responses: "Physical infrastructure (e.g., road design)", 11; "Higher trust from public (e.g., general public get used to driverless vehicle)", 11; "Established protocol (e.g., traffic policy, driving regulation)", 9.

DISCUSSION

In terms of drivers' knowledge about CAVs, almost all of the participants indicated that they were aware of the implementation of driverless vehicles, although they did not rate their knowledge very high on average. In contrast, more than half of the participants indicated very little or no knowledge of the concept of connected vehicles. The most frequent answer for where the participants learned about CAVs was through the popular media. These findings suggest that it may be possible to increase public awareness of the potential benefits of connected vehicles (reduced traffic congestion, fuel consumption, and transportation emissions; Yao et al., 2021) through exposure in popular media.

A positive message from the results is that many more people indicated that they thought that CAVs could share the road with HDVs than ones who thought they could not do so. This difference was coupled with a much larger percentage of the surveyed participants indicating trust in driverless vehicles and the AI controlling the vehicles than indicating distrust. An implication of these results is that drivers may be willing to accept CAVs on the roads if they can be shown to be safe.

For the types of specific intersections examined where interactions are needed, the results indicated that entering onto a crowded highway was of the most concern, followed by roundabouts and four-way stops. Use of traffic lights to signal when it is safe to proceed improved the rated safety for all intersection types, which is not surprising. That roundabouts were not ranked as the top concern was more surprising because they are usually considered to be challenging for both CAVs and human drivers (Gonzalez et al., 2017).

Another finding in the study is that for all intersections, there was a strong stereotype for preferring that standard vehicle visual signals be used by both HDVs and CAVs. This preference makes sense on many grounds with respect to human performance in general (Wickens et al., 2022) and driving in particular (Castro, 2008): Driving is primarily a visual task, and most attention is devoted to vision and not the other sensory modalities. Most signaling by vehicles is not done with words but with onsets and flashes at particular locations. Words may also suffer from legibility issues. These findings suggest that CAVs can be designed to communicate their intentions using current signaling methods, which drivers of HDVs can also use to signal their intentions to CAVs.

To summarize, based on the reports of the participants in this survey, who were sampled from across the U.S., it can be concluded that many people are willing to accept CAVs on the roads with HDVs, as long as safety and trust can be created. Considering the sample size, our study is not intended to be an exhaustive survey of all drivers in the U.S. Still, the results provide insight into the preferences and tendencies of human drivers toward machines. The preference indicated by respondents is for interactions with CAVs to proceed in much the same way as those with other HDVs. The tendency to accept CAVs likely can be increased by conveying to the public what the concept of connected vehicles entails and the potential benefits that connectivity can provide.

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