Survey on In-vehicle Technology Use: Results and Findings

Raj K. Kamalanathsharma, Hesham A. Rakha and Ismail H. Zohdy
Center for Sustainable Mobility, Virginia Tech Transportation Institute, 3500 Transportation Research Plaza, Blacksburg, Virginia 24061 USA.

ABSTRACT
The use of advanced technology in automobiles has increased dramatically in the past couple of years. Driver-assisting gadgets such as navigation systems, advanced cruise control, collision avoidance systems, and other safety systems have moved down the ladder from luxury to more basic vehicles. Concurrently, auto manufacturers are also designing and testing driving algorithms that can assist with basic driving tasks, many of which are being continuously scrutinized by traffic safety agencies to ensure that these systems do not pose a safety hazard. The research presented in this paper brings a third perspective to in-vehicle technology by conducting a two-stage survey to collect public opinion on advanced in-vehicle technology. Approximately 64 percent of the respondents used a smartphone application to assist with their travel. The top-used applications were navigation and real-time traffic information systems. Among those who used smartphones during their commutes, the top-used applications were navigation and entertainment.

Key words: Driver-assistance, In-vehicle technology, Public perception, Stated preference survey

1. INTRODUCTION
Use of technology in our daily life is increasing so rapidly that we see computers and computerized devices everywhere. As far as automobiles are concerned, where we once only had cruise control units, power windows, and remote lock/unlock devices in our vehicles, we now have navigation systems, voice-command operating systems, adaptive cruise control systems, and automated parking control systems. Researchers are also developing driverless vehicles, and transportation authorities in many countries are legislating inter-vehicular communications to enhance safety. For instance, the U.S. Department of Transportation started the Connected Vehicle research

*Corresponding author: Hesham A. Rakha, Tel: +1-540-231-1505, E-mail: hrakha@vt.edu

program, partnering with auto manufacturers and research universities to include more connectivity and technology in automobiles [1]. Auto manufacturers are equipping vehicle dashboards with more gadgets, while regulators such as the National Highway Traffic Safety Administration (NHTSA), citing safety reasons, are working towards new legislation that limits technology in vehicles [2].

For decades, researchers have been studying how to make driving more safe, fuel efficient, and comfortable. As a result, we now have vehicles that park themselves, cruise themselves, and even drive themselves. On the other hand, there are studies in which researchers analyze how effective or distractive these systems are. This has left a gap in research, namely, identifying what the end users want in their vehicles—more or less technology and the kind of assisting devices. An extensive background study suggested that most similar surveys reflect a non-scientific approach through publishing blog platforms or newspapers. All of these were consumer surveys that can be used as a comparison tool for different user interfaces and ease of use. The 2012 J.D. Power U.S. Initial Quality Study revealed that most of the complaints that new-car owners have relate to high-tech gadgets in their cars and how these gadgets interact with drivers [3].

Consequently, this paper is intended to fill the gap between the perceptions of end users and vehicle manufacturer implementations using statistics from a scientifically designed online survey implemented in two stages. These stated preference surveys were intended to solicit a sample population’s opinions on the use of advanced technology in automobiles. The first stage of the survey, conducted in 2012, highlights the generalized implications on how typical drivers react to equipping their vehicles with different levels of automation. In particular, two types of advanced cruise control systems were analyzed in this survey, namely Adaptive Cruise Control (ACC) and Cooperative Adaptive Cruise Control (CACC). The second stage of the survey, conducted in 2013, focused on identifying public opinion about the benefits sought from these advanced technologies. This survey highlights and ranks the aspects of driving or riding that the public would like to be automated.

A review of the literature reveals that most researchers have focused their efforts on testing the performance of new technology (e.g., advanced cruise control systems) and have assumed that drivers will accept such technologies. For example, some of the studies developed dynamic optimal speed advising algorithms on the vehicle side and compared system performance to actuated traffic signal control [4, 5]. For connected vehicles, many researchers have studied the impact of advanced cruise control (ACC and/or CACC) systems using simulation/simulator experiments (e.g., [6] and [7]). In addition, a few attempts in the literature have been made to create simulators (or simulation software) for modeling fully automated/autonomous vehicles (e.g., Dresner and Stone [8–10]).

However, a very limited number of researchers have attempted to study the impact of new technologies on driver behavior and driver distraction. In a NHTSA study, test vehicles with multiple vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) safety applications were tested using a total of 688 drivers, ages 20 to 70. The study concluded that, following the driver clinic, over 90 percent of the participants expressed a desire to have V2V communication safety features in their personal vehicles [11].

In the same context, the AAA Foundation for Traffic Safety (AAAFTS) in cooperation with the Automobile Club of Southern California (ACSC) conducted a survey to assess drivers' experiences with ACC systems [12]. The overarching goal of that study was to learn more about the extent to which ACC systems enhance or detract from safety. The results of this study showed that most of the ACC owners indicated that the system helped them to drive more safely; however, the younger respondents (less than 65 years old) were more likely to report a need for safety improvements to the system.

In summary, most of the previous research addressed advanced technologies in vehicles from an operations perspective and neglected driver acceptance and/or the behavioral adaptation of drivers. This paper attempts to overcome some of the previous research shortcomings by collecting public opinion on new in-vehicle technologies through a user survey. Specifically, the survey intended to rank the benefits of advanced in-vehicle technologies that are sought by average users as well as their intrusion into their driving space. The survey results are divided based on four major categories:

1. Smartphone Applications,
2. Advanced Cruise Control Systems,
3. Driver-assistance Systems and
4. Vehicle Automation.

2. STUDY OBJECTIVES

The objective of this research was to collect public opinion on the recent increase of in-vehicle technology and gadgets that are enabled by telematics and connected vehicle technology using two online surveys. In this study, two survey questionnaires were specifically designed to solicit public opinion on the desired level of advanced technology in vehicles and highway systems as well as to quantify the public's perception of these issues. While the phrase "technology in cars" could mean anything from Bluetooth to voice-command operations, this study deals with technology enabling safety and efficiency of driving. This includes systems such as ACC or connected vehicle applications using CACC systems.

Major demographic characteristics such as age group, gender, education, and occupation were used to classify the responses and to draw statistically significant results. This survey is intended to address some questions regarding public acceptance of various driver-assistance systems and levels of vehicle automation. Some of these are:

1. Identifying possible demographic characteristic effects (age, gender, etc.) on driver acceptance of in-vehicle technologies;
2. Soliciting driver input on the intrusion of smart phone applications in transportation;
3. Ranking the various types of systems that drivers like or dislike in their vehicles;
4. Soliciting driver acceptance regarding various levels of vehicle and highway automation.

As far as the paper layout is concerned, the survey methodology is described along with sampling the population characteristics, design and implementation of the survey, and post-survey adjustments. An extensive section on the findings from this survey is provided along with charts of major public responses and a list of major conclusions.

3. METHODOLOGY

Advanced automobile technology is primarily controlled by two parties: the automobile manufacturers and governing authorities. The automobile manufacturers are equipping vehicles with driver-assistance devices (including forward collision warning [FCW] systems, drowsy driver sensors, etc.) and the governing authorities such as NHTSA are developing regulations to ensure that such systems do not produce a safety hazard. Between these two parties, there are 211,000,000 licensed drivers in the United States (as of 2009) who will be the actual end users of such systems [13]. The research presented in this paper solicited a sample of drivers in the United States for their perceptions of advanced in-vehicle technologies and what types of innovations in transportation they would like to see.

Scientifically designed online surveys are considered an effective and quick tool to collect responses from a variety of audiences. The surveys used in this study had the following stages of implementation:

1. Sample size computation: This was done primarily to define the statistical significance of the study. The sample size was derived from the population size as well as confidence intervals and levels.
2. Design of questionnaire: The questionnaire was designed to incorporate the questions that would yield necessary data for the research in a set of easy-to-read plain English questions. Any technical descriptions were simplified to ensure layman understanding.
3. Seeking necessary approvals: As per institutional requirements, some survey review and approval was necessary since this research involved human subjects.
4. Invitations and publicity: This step was of utmost importance in the overall success of the survey. It involved solicitations through known listservs, electronic mailing lists, and social networking groups. Survey respondents were volunteers who chose to respond to the posting.
5. Survey closure: Once the number of respondents reached the desired sample size plus some buffer considering the potential for incomplete responses, the survey was removed from the Web.
6. Data analysis: The responses collected during the open period were post-processed to remove any incomplete responses. The final processed data were then analyzed to derive conclusions.

3.1. Sampling

The sample size required for the survey to be statistically significant is calculated using the following equations.

$$x = \left[z\left(c/100\right)\right]^2 \times r \times (1-r) \quad (1)$$

$$n = \frac{Nx}{(N-1)E^2 + x} \tag{2}$$

where N is the population size, r is the fraction of response of interest, $Z(c/100)$ is the critical value for the confidence interval c, and E is the margin of error allowed. Assuming the population's response is not skewed and the sample is random, we consider an r-value of 0.5. A confidence interval of 5 percent and a confidence level of 95 percent will yield a minimum required sample size estimate of 385, where the population size is assumed to be all licensed drivers in the United States over the age of 18. Table 1 shows the number of licensed drivers in the United States based on the 2009 census (the latest available) [13]. Only drivers of age 18 and above were considered for the survey due to Institutional Review Board (IRB) requirements.

3.2. Survey Design

Since the survey population consists of any licensed driver in the United States, the survey questions were designed to be simple and easy to understand. The first survey was conducted in 2012 and spanned nearly 4 weeks. The survey was designed to provide valuable statistics showing the relationship between demographics and drivers' perceptions of increased in-vehicle technology and their acceptance of future systems. The second survey in 2013 was specifically designed to expand on the benefits that end users are receiving from the current level of technology and the perceived benefits of future systems.

The survey population was solicited using emails to known listservs as well as social networks and tweets. IRB approval was sought and received for the specifically designed questionnaires and the survey process. As per IRB requirements, respondents less than 18 years of age were not included in the study. The masking of any identifying information about respondents, including response location and IP address, was a requirement for IRB approval.

3.3. Post-Survey Adjustments

The surveys were online for over 4 weeks collecting survey responses from respondents who volunteered to fill out the questionnaire. There were some adjustments that were done after survey closure. They are listed here:

1. Responses with empty answers were removed. This included responses with any question left unanswered.
2. In some questions, the respondents could type out their own answers rather than selecting a given choice. Some of these answers were similar to the responses that could be selected. These options were merged.
3. Answers that were not part of and different from the choice set were individually categorized, putting similar views together.
4. Responses were linked based on certain demographics and respondent areas of expertise so that meaningful conclusions could be made.
5. Post-stratification weights were used to adjust the responses to match the actual population. The adjustment also helped to form matching demographics for both surveys. This will be explained in the following subsection.

4. SURVEY RESULTS AND FINDINGS

Post-processing yielded a set of over 400 survey responses for each of the surveys, which was well over the minimum sample size required. However, the demographic distribution has to be matched between the surveys and with the population in consideration. Post-stratified weights were used to match the stratified sample proportions to the population distribution given in Table 1a. This method expanded the responses from the age groups that had lesser responses (over 65 years) and contracted the responses from the age groups that had the most responses (25 to 40 years). While post-stratification could be done based on several factors including socioeconomic ones, age is being considered here since the socioeconomic distribution of the licensed U.S. population consists of multiple variables that need factored weighing. Table 1b shows the calculation of post-stratification weights for making the respondent population comparable with the actual population of licensed drivers in the United States aged 18 and above. Since the respondent strata are different for Part 1 and Part 2 of the survey study, they have different stratification weights.

These weights were then used to weigh the responses to the survey made by the respondents based on their age group. The weighted results are considered to replicate the actual population's behavior (Table 1a). Stratification also aligns the respondent demographics of the second part of the survey with the actual population, thereby making the results from both surveys comparable. In order to preserve the demographic representation of the population under consideration, no trimming was made on the weights and hence the number of weighted responses was equal to the

Table 1a. Population distribution of licensed drivers in U.S. (2009 census data)

Age Group	Number of Licensed Drivers	% of Population
18 to 24	23,647,000	11.43
25 to 40	55,906,000	27.02
41 to 65	94,404,000	45.63
Over 65	32,899,000	15.92
Total (18 and up)	206,856,000	100.00

Table 1b. Post-stratification of survey respondents

Age	Pop.	Sample Proportion		Stratification Weight	
Group	Ratio	Part 1	Part 2	Part 1	Part 2
18–24	0.114	0.212	0.242	0.54	0.47
25–40	0.270	0.645	0.450	0.42	0.60
41–65	0.456	0.122	0.290	3.74	1.57
Over 65	0.159	0.021	0.018	7.57	8.83

number of actual responses. In the following sections, survey results based on different criteria are explained.

4.1. Demographics

Figure 1 shows the demographic distribution of survey respondents with respect to age, gender, education level, and car usage. The dissimilarity in age distribution was negotiated by the post-stratification process. The prominent respondent education level was a four-year college degree and had a 35:65 gender split as shown. Over 87 percent of the respondents drove more than twice a week. Other demographic features are also shown in Figure 1. It was also seen that there is a bias between the education demographic and gender. For example, only 6 percent of the respondents listed their highest education as being less than a four-year degree. Therefore, a chi-squared test was performed to see if the responses were independent of the respondents' education or gender.

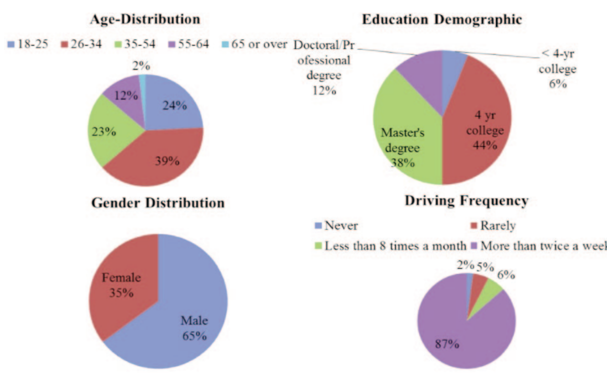

Figure 1. Distribution of respondent population based on demographics

Independence tests using Pearson's chi-squared test were done with the test variables being whether the respondents support advanced technology in automobiles and what level of highway automation is desired. The test factors were age group, gender, education, and the respondent's area of expertise. Table 2 shows the chi-squared values for a significance level of 0.05. Tests indicate that the responses were independent of respondent demographics. In other words, the demographic characteristics of the participants (respondents) did not affect their responses concerning the support of technology or the desired level of highway automation. It could be stated that many of these results are consistent with a previous study [12].

The survey also identified the most common commute mode among the respondents to which the results can be associated. The responses to the frequency of use of each transport mode were recorded for this purpose and were then weighted to rank them according to how often they were used. This ranked list is given below:

1. Car/Truck/Motorcycle
2. Walk
3. Transit Bus
4. Bike
5. Metro/Light Rail
6. Heavy Rail

Table 2. Population distribution of licensed drivers in U.S.

	Support technology in vehicles		Desired level of highway automation	
	Chi-squared	Prob > Chi Sq.	Chi-squared	Prob > Chi Sq.
Age	3.279	0.9932	18.064	0.1138
Gender	5.504	0.2394	9.228	0.0556
Education Level	11.402	0.7840	21.465	0.1613
Area of Expertise	6.049	0.1955	4.473	0.3457

4.2. Smartphone Applications

There has been an increasing trend of smartphone applications that help with multiple aspects of transportation. Smart-navigation, real-time traffic information, weather information, etc., are just a start of the growing influence information technology has on the way people commute. Though using cellphones while driving is discouraged and even legally banned in many states, smartphones contribute to bringing real-time information to drivers so that they can make informed choices on routes and modes. Around 64 percent of the survey respondents have used smartphones to help with their commutes in some way.

Figure 2 shows the top smartphone applications that are used in connection with commuting and travel. While commuting and other kinds of travel have identified different sets of data-needs and driving behavior, in this study, they are considered together since some of the categories do not apply to commuting. For example, most

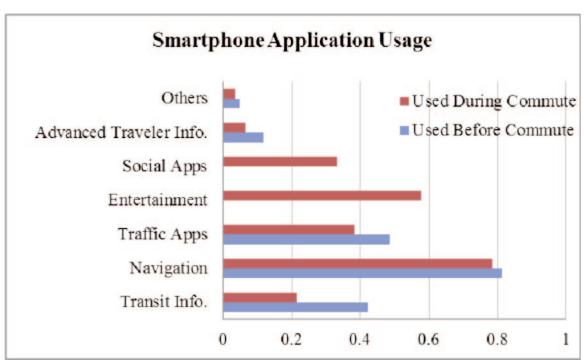

Figure 2. Smartphone applications that are used in connection with commute/travel.

commuters are familiar with their route and therefore would not use navigation applications. Smartphone applications are ranked based on the percentage of respondents who have used them. Navigation applications held the top position, with nearly 80 percent of people using them both prior to and during the trip. Traffic and transit applications held the next positions for the top apps that were used by the respondents to help with their trips. As far as the applications that are used by respondents during trips are concerned, entertainment and traffic applications followed navigation apps in ranking. It should be noted that social apps and entertainment apps that were used prior to commuting were dropped since they rarely help with trip decisions.

4.3. Advanced Control Systems

A variety of vehicle control systems have been recently introduced in the market under different trade names as we move closer to self-driving vehicles. For example, ACC can detect slowing lead vehicles and adjust the speed accordingly to maintain a safe headway. CACC communicates with neighboring vehicles for more responsive safety applications, including red-light running and intersection collision avoidance. In contrast to these advances, the results from the survey reveal that adoption of traditional cruise control has been mixed with nearly 20 percent of the respondents never using it. However, 34 percent of respondents use cruise control whenever possible. Figure 3 shows the statistics on whether the respondents use traditional cruise control while driving and whether they are aware of the new advancements in cruise control technology. In order to test public awareness of the new types of assistive cruise control systems, respondents were asked if they were aware of ACC systems. An approximately 50:50 split was shown in the responses. This indicates the respondents' average knowledge about the new technologies coming up in the transportation industry.

The penetration level of any new technology that affects how people drive depends on its trustworthiness. Most survey respondents highlighted the importance of "learning" in their perceived trustworthiness of advanced technology in driving-assistance systems. Around 15 percent of the survey respondents did not trust the two

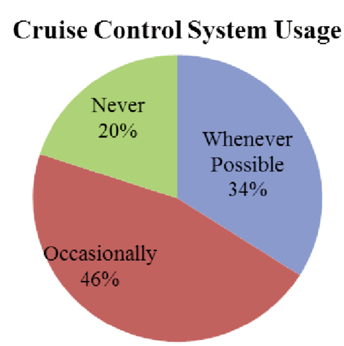

Figure 3. Percentage distribution of how often respondents use cruise control while driving

advanced cruise control systems, namely ACC and CACC. The survey questionnaire provided brief descriptions of these systems so that respondents could make judgments. ACC maintains a constant headway by detecting the speed of the lead vehicle and CACC adjusts cruise speeds using advanced information from surrounding cars and infrastructure equipment. These results are shown in Figure 4.

As far as the statistics are concerned, 49 percent of the respondents had heard about ACC systems. Figure 4 shows the perceived trustworthiness of these two types of cruise control systems to the public. A total of 64 percent of the respondents would trust ACC systems after using them. This learned trustworthiness is approximately 55 percent for CACC systems. A total of 14 and 13 percent of the respondents indicated that they would trust these respective systems if they were available for use by the public. Around 7 and 14 percent, respectively, thought they might trust these systems after studying safety reports and consumer reviews, and less than 1 percent had views that were not listed in the questionnaire, most of which reflected the opinion that it was not an issue of trustworthiness but an issue of need.

Anti-distracted driving has been the primary safety campaign by NHTSA and other traffic safety organizations. Recent studies have indicated that high-tech gadgets add to driver distraction [14]. This survey also analyzed public perception on driver distraction as a result of technology. In one question, respondents were asked if they thought they were distracted while using cruise control. A summary of the results is shown in Figure 5. Only 24 percent of the respondents agreed that they were more likely to be distracted while using cruise control. Around 44 percent of the respondents thought cruise control and driver distraction were unrelated, and 28 percent of the respondents had a neutral opinion.

4.4. Driver-Assistance Systems

Vehicle control systems are just a part of some of the automation we see in today's cars. Automobile companies are equipping vehicles with multiple systems to make driving and riding more comfortable, entertaining, and economical. The survey respondents were asked to rank the types of systems they would want in their vehicles, and the

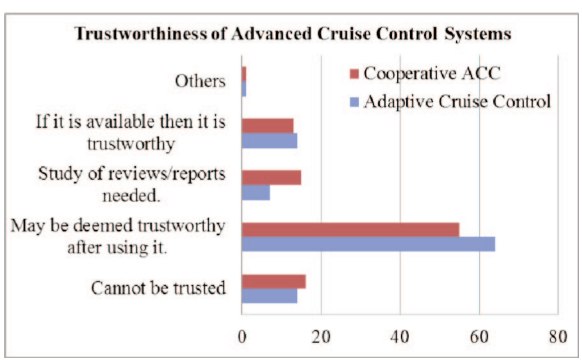

Figure 4. Percentage distribution of trustworthiness of advanced cruise control systems

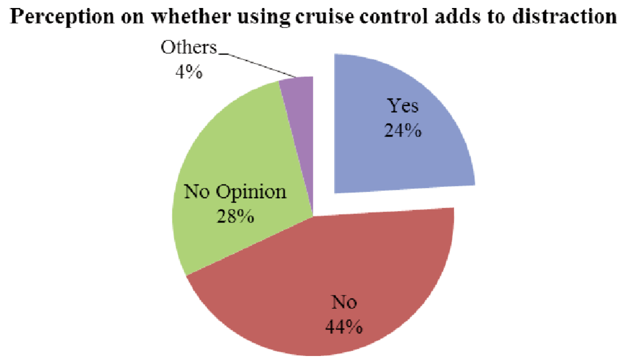

Figure 5. Effect of using cruise control on distraction while driving

results are given in Figure 6a. Systems that enhance the safety of passengers were ranked at the top by over 60 percent of respondents. The second highest-ranked systems were those that make vehicles more fuel efficient. The entertainment and social systems that are being added by some of the manufacturers came the lowest on the ranking, with over 75 percent respondents marking them as least important.

In order to perceive what benefits end users expect from advanced driver-assistance applications, the respondents were asked to rank benefits (shown in Figure 6b). Rank-weighted responses were used to give overall rank to all of the systems and were computed as the sum of the products of the number of responses with their corresponding ranks. These benefits were consequently ranked in the following order:

1. Enhanced safety
2. Reduced travel time and delays
3. Fuel economy
4. Driver and passenger comfort
5. Reduced workload while driving

Additionally, the respondents were asked if they were in favor of adding more technology to automobiles. Over 89 percent of the respondents supported more technology in automobiles, with around 45 percent strongly supporting this idea. Only 3 percent of all respondents opposed increased use of technology in automobiles. These results provide valuable input for researchers working on developing driver-assistance systems as to what areas to focus development on. Consequently, these results indirectly show the hierarchy of the price that users would pay for these systems.

4.5. Vehicle Automation

Numerous labs and research groups are in the process of developing autonomous driving systems. As guidance, NHTSA has identified major milestones on the way to fully automated vehicles. Five levels of automation have been identified currently, as given in Table 3. Specific definitions of these terms are available in [15]. The survey presented in this paper attempted to address the public perception of an automated

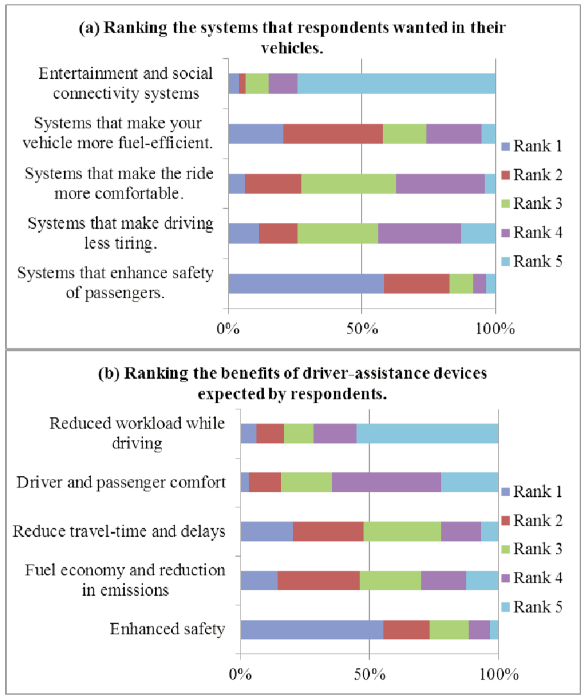

Figure 6. Respondent ranking of various driver assistance systems and the benefits sought from them

driving environment. While the definitions of these levels are too complex to be explained in layman's terms, the survey used well-defined systems that can cover these five milestones. Respondents rated how much they would want these systems. The following system definitions were used in the research:

- System 1: Systems that provide information about the trip, such as routes, congestion, incidents, etc.
- System 2: Systems that assist with driving, such as signal timing information, blind-spot occupancy, etc.
- System 3: Systems that enhance safety, such as automated braking systems, collision avoidance, etc.
- System 4: Systems that enable automated highway driving using lane centering and safe headways.
- System 5: Self-driving systems which need no human input other than destination.

Figure 7 shows the public perception of the aforementioned systems. As shown, as the system becomes more and more complex and intrusive, the drivers are less receptive to the system. For example, nearly 90 percent of the respondents are receptive to System 1, which does not intrude on the driver's role whereas only 33 percent of the respondents are receptive to a self-driving system (System 5).

Table 3. Various levels of automation as identified by NHTSA

Level	Description
0	No Automation
1	Function-specific Automation
2	Combined Function Automation
3	Limited Self-Driving Automation
4	Full Self-Driving Automation

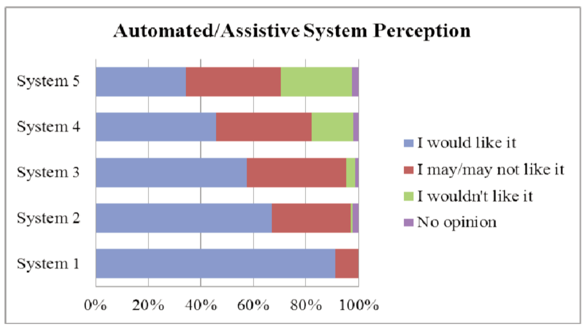

Figure 7. Respondent opinions on various levels of automation systems

5. CONCLUSIONS

The survey conducted and analyzed in this paper evaluates the public perception of increased technology in vehicles and highway systems. The two-part survey covered multiple facets of advanced technology in driver-assistance devices. Results from this study are expected to help researchers focus their research into the latest innovations in connected vehicle research and advanced vehicle systems. The results could also be used by auto manufacturers in critical decisions regarding equipping vehicles with in-vehicle gadgets. The stated preference survey responses were able to yield a confidence interval of 5 percent and a confidence level of 95 percent. Post-stratification was done to match the respondent population's age groups with the actual population's age groups.

Findings from the survey highlight the following conclusions:

1. Demographic factors such as age, gender, and education had no impact on the respondents' answers to questions regarding in-vehicle technology.
2. Approximately 64 percent of the respondents had used a smartphone application to assist with their travel. The top-used applications were navigation and real-time traffic information systems.
3. Among those who used smartphones during their commute, the top-used applications were navigation and entertainment.

4. More than 24 percent of respondents thought that they were more distracted while using cruise control. As far as the trustworthiness of advanced cruise control systems such as ACC and CACC systems is concerned, up to 60 percent of the respondents felt that they would need to get acquainted with these systems before making a judgment. This conclusion may be true with any new innovation.
5. The top driver-assistance systems that respondents voted for are systems that enhance the safety of passengers and systems that make vehicles more fuel efficient. Among the benefits that the respondents sought from advanced driver assistance systems, the top ones were enhanced safety and reduced travel time and delays.
6. Advancements in social and entertainment systems in the vehicles were ranked lowest by the respondents.
7. More respondents voted for systems that are non-intrusive (over 90 percent) than fully autonomous (35 percent).

These conclusions are expected to help bridge the gap between the advancing research and development of in-vehicle technology, including vehicle automation, and public expectations of those technologies.

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