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16. Abstract

Seat belt use is critical in mitigating injury severity and road fatalities from motor vehicle crashes. The design of a seat belt assurance system (SBAS) aims to promote more seat belt use, especially among drivers who do not have the habit of always using seat belts. This study was conducted to evaluate how part-time seat belt users interact with two prototype SBASs, a transmission interlock system and a speed limiter system, under naturalistic driving settings. A total of 48 part-time seat belt users participated and each participant was given one type of the SBASs for three weeks, one baseline week (i.e., the SBAS was not turned on), and two treatment weeks (i.e., the SBAS was activated). Data on participants' driving behavior and their interactions with the SBAS was collected and along with subjective ratings were used in the final analysis. The results showed statistically significant improvement in seat belt use for both SBAS types such that the percentage of unbelted driving time (or trips) significantly decreased during the treatment period as compared to the percentage of unbelted driving time (or trips) during the baseline period. The average treatment period related reduction in unbelted driving time was about 14.4 percent while the reduction in unbelted trips was about 19.8 percent. High user acceptance was also observed that in general participants perceived the benefits during their experience with the technology. About 95 percent of drivers agreed or strongly agreed the technology was easy to use.

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1. Executive Summary

The purpose of this study was to evaluate the potential effectiveness and user acceptance of two prototype seat belt assurance systems (SBASs), as well as observe any system-defeating behavior exhibited by drivers. The University of Michigan Transportation Research Institute (UMTRI) and two participating original equipment manufacturers (OEMs) collaborated on a field operational test to collect data on how drivers interact with SBASs in a real-world setting and their attitudes towards those systems. Western Transportation Institute (WTI), as a subcontractor to UMTRI, has summarized the literature and examined the user acceptance. In this research, the terms "seat belt assurance system" or "seat belt interlock" are broadly defined as a mechanism that restricts some vehicle functionality (permanently or temporarily) given a predetermined set of conditions (e.g., detection of unbelted occupants for a given time).

Two types of research vehicles equipped with distinct prototype SBASs were used in this study, including a transmission interlock system and a speed limiter system. The transmission interlock system prevented a vehicle that has just had its ignition turned on from being shifted into gear if either the driver or front seat passenger is unbelted. The speed limiter system limited maximum vehicle speed with an unbelted driver or unbelted front-seat passenger to speeds below 15 mph.

A power analysis was performed and employed a mixed design that included 48 part-time seat belt users. Half the participants were randomly assigned to the speed limiter group while the other half were assigned to the transmission interlock group. Each participant was given one type of research vehicle for three weeks, including one baseline week (i.e., the SBAS was not turned on), and two treatment weeks (i.e., the SBAS was activated). Data on participants' driving behavior and their interactions with each seat belt assurance system was collected over the three-week period and along with subjective ratings were used in the final analysis.

The results showed statistically significant improvements in seat belt use for both SBAS types such that the percentage of unbelted driving time (or trips) significantly decreased during the treatment period as compared to the percentage of unbelted driving time (or trips) during the baseline period. The average treatment period related reduction in unbelted driving time was about 14.4 percent while the reduction in unbelted trips was about 19.8 percent. The 48 participants were divided into two groups based on their seat belt use during the baseline week, frequent seat belt users with a 90 percent or greater belted driving time and infrequent seat belt users with a lower than 90 percent of belted driving time. This effectiveness was more pronounced for infrequent belt users than for frequent belt users.

Comparative differences between the two SBAS systems were observed with different measures (i.e., based on unbelted trips or unbelted driving time). The decrease in the percentage of unbelted trips (between treatment and baseline driving) for the speed limiter group was much less than for the transmission interlock group. However, with the measure of unbelted driving time, similar reductions were observed for both SBAS groups. We suggest that the measure of "percentage of unbelted driving time" may be a better indicator of system effectiveness because it includes total trip duration, factoring overall exposure into the analysis.

Two main system-defeating or “cheating” strategies were observed, pre-buckling then sitting on the seat belt and waiting out the transmission interlock timer. Eight drivers, all infrequent seat belt users, cheated the SBAS during treatment driving. Drivers from the transmission interlock group tended to be more likely to cheat the SBAS than drivers from the speed limiter group (odds ratio =2.5). Drivers were three times more likely to cheat during treatment condition than during baseline condition (odds ratio =3).

Generally, high levels of user acceptance were observed as participants rated their experience with the technology in terms of perceived benefits (including resulting attitudes) and ease of interaction. Nearly all drivers agreed or strongly agreed the technology was easy to use (95%). There was no significant difference in the reported ease of use between the two SBAS technologies.

2. Background and Research Objectives

Seat belts are one of the most important motor vehicle safety devices that have been developed. It has been widely reported that the use of seat belts is one of the most effective methods of reducing injury severity and road fatalities in motor vehicle crashes (Evans, 1996; Jonah, 1986; Liu et al., 1998). Of the 22,441 passenger vehicle occupants killed in motor vehicle crashes across the United States in 2015, some 48 percent were unrestrained (NHTSA, 2016). It has been estimated that front-seat seat belt use has reduced the fatal injury risk for occupants by 45 percent, and the moderate-to-critical injury risk by 50 percent (NHTSA, 2009). In 2010 the use of seat belts prevented 12,500 fatalities, 308,000 serious injuries, and $50 billion in injury related costs (Blincoe, Miller, Zaloshnja, & Lawrence, 2015).

All States in the United States except New Hampshire have enacted legislation that mandates the use of seat belts for adults. The enforcement of mandatory seat belt laws has greatly increased seat belt use (Carpenter & Stehr, 2008; Eby, Molnar, & Olk, 2000; Solomon, 2002). Seat belt use has increased from 54 percent in 1994 to more than 89 percent in 2018 (NHTSA, 2019). Further increases in seat belt use for front-seat occupants (to near 100%%) would continue to produce substantial reductions in injuries and fatalities. However, recent increases in seat belt use have been modest, suggesting that there is some residual need for new seat belt use enforcement. In 2012 the Moving Ahead for Progress in the 21st Century (MAP–21) law removed the restrictions that had prohibited NHTSA from prescribing a motor vehicle safety standard that required, or permitted as a compliance option, ignition interlocks designed to prevent starting or operating a motor vehicle if an occupant was not using a seat belt.

Passenger vehicle seat belt interlock technology has been suggested as a promising way to further promote seat belt use, since it can continuously monitor belt use and provide immediate feedback whenever an occupant is unbuckled (Kidd, McCartt, & Oesch, 2013). Two main issues, among others, need to be addressed in the design of any in-vehicle seat belt interlock technology: (1) system effectiveness defined by user compliance, and (2) system usability defined by user perceptions of acceptability, satisfaction, and willingness to purchase. Thus, a successful seat belt interlock system should not only effectively increase seat belt use, but also achieve a certain level of user acceptance for all drivers. Another important issue, not addressed by this study, is the extent to which an interlock needs to be designed to prevent intentional misuse, i.e., cheating the system.

The importance of user perceptions should not be underestimated. The negative opinion of ignition interlocks in the early 1970s may still prevail. Eby et al. (2004) conducted a series of focus group studies with part-time seat belt users. They found that seat belt ignition interlocks were still perceived to be unacceptable by most people. Other studies have been conducted to evaluate whether less intrusive types of seat belt interlocks are more acceptable than the ignition interlocks. Van Houten et al. (2011) conducted a pilot test of a new application of accelerator pedal pulse intervention with commercial fleet drivers. In the study, unbelted drivers experienced sustained haptic feedback from the accelerator pedal when they exceeded 25 mph. Drivers were obliged to press on the pedal harder to exceed 25 mph when unbelted. The resistance feedback was removed when drivers put their seat belts on. The haptic feedback was reported to be effective in prompting drivers to buckle up, and most drivers found the approach acceptable.

Another interlock technology was also tested that delayed unbelted fleet drivers from shifting vehicles into gear for up to 8 seconds (Van Houten et al., 2010). A significant increase in seat belt use was observed with this technology, although most drivers reported that the system was annoying.

A recent national telephone survey study conducted by IIHS collected information about drivers' attitudes toward different types of in-vehicle seat belt interlock technologies (Kidd et al., 2013). The four types of interlocks evaluated in the study included an ignition interlock, a speed interlock that limited vehicle speed to 15 mph if the driver was unbuckled, a transmission interlock that prevented the vehicle from being placed into gear if the driver was unbuckled, and an entertainment system interlock that disabled the audio entertainment system if drivers were unbuckled. Results showed that part-time belt users and non-users had a less positive view of each type of interlock than full-time belt users. Among the four interlock systems, ignition interlock had the lowest support from drivers (44 percent support), followed by entertainment system interlock (47 percent support), transmission interlock (51 support), and speed limiter interlock (51 percent support).

Federal regulations require vehicles to be crash tested with test dummies in belted and unbelted conditions. It was found that self-reported usage of seat belts was related to the amount of perceived risk of injury from not wearing a seat belt, which was reportedly lower for rural drivers – especially those who primarily drive pickup trucks (Rakauskas, Ward, & Gerberich, 2009). Thus, those subgroups of drivers who do not wear seat belts because they believe there is no risk for non-compliance will have a fundamentally different attitude toward technologies and policies that demand wearing a seat belt (compliance). For this reason, it is necessary to test such technologies with low and high compliance groups and examine the cultural basis of those differences in compliance.

This study conducted the first field operational test to investigate prototype seat belt assurance systems that involves part-time seat belt user populations interacting with the different types of interlocks. Tests that collect both objective (observed compliance) and subjective (acceptance) data are essential to help determine which interlock technologies are most likely to further improve driver safety. The objective of this project is to collect and interpret data related to seat belt "assurance" (interlock) system use to examine system effectiveness, user acceptance, and to identify any unintended consequences associated with their use.

3. Literature Review and Stakeholder Outreach

This study started with a review of the literature and current practices on seat belt use and seat belt interlock systems or SBAS. An SBAS is broadly defined as a mechanism that restricts some vehicle functionality (permanently or temporarily) given a predetermined set of conditions (e.g., unbelted driver detected). Based on our initial literature search, SBAS concepts include transmission interlock (e.g., to prevent unbelted drivers from shifting into gear with or without delays), speed limiter (e.g., to prevent unbelted drivers from driving above a pre-set speed), accelerator interlock (e.g., to add pedal pulse to prevent an unbelted driver from accelerating), entertainment interlock (e.g., to prevent the use of the radio or A/C if the driver is unbelted), and ignition interlock (e.g., to prevent unbelted drivers from starting the car).

In the United States, seat belt use has increased from 58 percent in 1994 to about 89.7 percent in 2017, and it continued to be higher in States in which vehicle occupants can be pulled over solely for not using seat belts ("primary law States"), as compared with States with weaker enforcement laws ("secondary law States") or without seat belt laws (NHTSA, 2018). In the telephone survey conducted by the Insurance Institute for Highway Safety (IIHS), 91 percent of respondents were found to be full-time seat belt users, 8 percent were part-time users and the remaining 1 percent were non-seat belt users (Kidd et al., 2013). In further research on buckling patterns of seat belt users, about 90 percent of full-time belt users buckle up before the vehicle is moving (Malenfant & Van Houten, 2008), compared with around half of all part-time belt users. About one-fifth of part-time belt users buckle up after the vehicle is moving. However, another one-fifth said their buckling routines vary (Kidd et al., 2013).

Reasons for Non-Use of Seat Belts

Non-use of seat belts is often characterized as a habitual behavior rather than a conscious choice (Calisir & Lehto, 2002,). Habitual behavior is understood to be routine, automatic, and largely subconscious (Behavioral insight toolkit, Department of Transport, UK) developed largely based on experience; whereas conscious choice is continuously comparing risks against benefits in deciding whether to buckle up. The habit of wearing a seat belt is learned and can be influenced by the behavior of others, including parents, peers, and children because of social learning theory (Harrison et al., 2000; Shinar, 1993; Grusec, 1992). Similarly, non-users may have failed to develop belt-wearing habits or have developed a habit of non-use (Harrison et al., 2000).

Belt use may also be situational. This is particularly characteristic of part-time users, who may be cued to buckle up in some driving situations, but not in others (Harrison et al., 2000). Many part-time users interviewed by NHTSA (Humphrey, 2003) and in earlier focus groups reported that they did not wear seat belts in what they considered low-risk situations (Bentley et al., 2003; Bradbard et al., 1998). These include short trips on familiar roads at relatively low speeds. However, these situational users tended to buckle up in poor driving conditions, such as bad weather, on longer trips involving high-speed driving on Interstates, and under congested conditions where other drivers could pose a danger (Bentley et al., 2003).

Belt use behavior may also stem from attitudes and beliefs. Non-use of seat belts has been related to risk-taking and other problem behaviors such as substance abuse (Wilson, 1990). It was reported that nighttime seat belt use among fatally injured occupants was substantially lower than daytime use over years (Tison, Williams, & Chaudhary, 2010), which indicated that part-time users are more likely not to use seat belts at nighttime than during daytime. In addition, many non-users object to being forced to buckle up, believing that belt use should be a matter of personal choice (Bentley et al., 2003). Belt use is also affected by ease of use and comfort of the belt system. For example, research conducted by IIHS (Kidd et al., 2013) concluded that major reasons for non-use by part-time users were short trip duration (67%), followed by forgetfulness (60%), and comfort (47%). In the case of non-users, the major reason is comfort (77%), followed by not liking to wear the seat belt (54%) and not liking being told to wear the seat belt (50%). In response, efforts to improve the ease and comfort of belt use by optimizing the seat belt height and tension adjusters and improved seat belt access have been introduced in the passenger vehicle fleet (Humphrey, 2003).

Seat belt non-use is also affected by gender and age. In the case of gender, females have a higher rate of observed seat belt use (79% of the time compared to 72% of the time for males) (Glassbrenner, 2003). In the case of the effect of age on seat belt use, people in the age group 21 to 24 have the lowest rate of belt usage, while those older than 65 have the highest rate of usage (Block, 2001).

Seat Belt Interlock Systems – History

The MAP-21 legislation enacted in 2012 eased the restrictions on NHTSA, allowing it to propose the use of interlock systems as a voluntary option to meet Federal safety requirements. However, the prohibition against an interlock requirement remains. FMVSS 208, Original Occupant Protection Requirements, was one of the 19 original Federal Motor Vehicle Safety Standards that required passenger cars to provide a seat belt at every forward-facing designated seating position. This requirement took effect on January 1, 1968. In 1970, NHTSA published a final rule that required automatic crash protection for all passenger cars as of July 1, 1973. The two types of automatic crash protection that were proposed for sale on production vehicles were automatic seat belts and air bags. Also, if the vehicles were not equipped with the automatic protection units, it was required for the vehicle to be equipped with an interlock system. At this time, the first ignition interlock system was adopted (Kratzke, 1995). The interlock system prevented the start of the vehicle until the seat belt was buckled, which resulted in high seat belt use, and led to public outcry (Kidd, McCartt, & Oesch, 2013); in 1974 Congress banned NHTSA from mandating seat belt interlocks or allowing them to be used to meet a safety standard (Motor Vehicle and School Bus Safety Amendments of 1974, 1974), and prohibited them from requiring an auditory belt reminder lasting longer than 8 seconds.

Types of Seat Belt Interlock Technologies

There have been significant changes and enhancements to ignition interlock technology since the first systems were developed in the early 1970s. The devices have become more compact and reliable. As a result, the devices are also more user-friendly and difficult to bypass (Van Houten et al., 2011). This section describes the current technologies in use for the five types of interlock systems. It also discusses the limitations of the devices, which affect public acceptability and user willingness to bypass the systems.

Ignition Interlock System. A seat belt ignition interlock system typically consists of a seat belt heat sensor located on the front portion of the seat belt, and an ignition interlock clip circuit that contains the seat belt clip, which work together to control the ignition of the vehicle. The sensor detects the body heat of the occupant; it emits a signal regarding whether the belt is properly strapped across the occupant's body. The seat belt clip is basically an ignition switch connected to the engine starter mechanism; when the seat belt is fastened, it completes the electrical circuit that allows ignition of the engine (U.S. Patent No. 20,110,203,866, 2011). Ignition interlock systems have several limitations, such as they do not allow remote starting of vehicles and users tend to bypass or override the system to avoid the inconveniences (NHTSA, 2013).

Speed limit Interlock System. This type of interlock system works by limiting the maximum driving speed of the vehicle if the driver is unbuckled to a pre-set speed value (i.e., 15 mph) (Kidd et al. 2013). This system includes a sensor unit that detects the weight of the occupant. When the occupant is seated, the sensor emits a signal indicating that the seat is occupied. The signal is transmitted to the seat belt monitor unit that receives both the occupancy signal and a buckled seat belt signal (using a magnetic switch located in the buckle). If the seat is occupied but the seat belt is unbuckled, the system emits an alarm signal. A handicapping unit (using a program operating on the vehicle's standard onboard computer) receives the unbuckled seat belt alarm signal and adjusts the operation of the automobile by limiting the speed to a pre-set level (typically 15 mph) (U. S. Patent No. 7,686,119, 2010). One principle limitation of this interlock system is that it can unexpectedly slow road traffic around the vehicle.

Accelerator Pedal Interlock System. This type of interlock system works by requiring increased force on the accelerator pedal to main certain driving speed. This apparatus includes a microprocessor installed under the driver's seat, which is connected to six functions of the vehicle using a specially designed harness, as well as two weight sensors located under the driver's seat. The microprocessor records all of the data. A separate circuit activates a stepper motor that manipulates the accelerator pedal when the seat belt is not buckled. A stepper motor is an electromechanical device that converts electrical pulses into discrete mechanical movements (Altintas, 2009). A potentiometer measures the force on the accelerator pedal position. The stepper motor is placed under the vehicle's dashboard so that the piston head is in contact with the flat metal disk of the accelerometer. The piston can remain in contact with the affixed disk across the full travel of the accelerator pedal, from fully up to fully depressed (Van Houten et al., 2011). A major limitation of this technology could be that drivers grow tired from the continued application of force to the accelerator. In addition, there is no system to inform the driver of the system's presence until the driver starts using the vehicle unbuckled (Von Houten et al. 2011).

Transmission Interlock System. This system acts by delaying the unbelted driver from shifting into gear. The apparatus includes a microprocessor installed under the driver's seat, which is connected to seven functions of the vehicles via a specially designed harness, as well as a chime and seat sensor. This microprocessor records data and includes a programmable gearshift delay plus a seat belt reminder. The delay begins after the driver applies the brake to put the transmission in gear. The system's designed delay in gear shifting could lead to frustration among the users, limiting the car moving within short distance for unbelted users (Van Houten et al. 2005).

Entertainment Interlock System. The Entertainment Interlock System, also known as the audio system seat belt safety device, can be installed in the seat and connected to the audio system of the vehicle. The system can detect when a person is seated through the weight sensor, and the audio system will not have power until the seat belt is engaged. Once the seat belt is buckled, power will be applied to the audio system. Potential problems with driver behavior might involve this system leading to unsafe driving among users due to anxiety, frustration and anger created by the interlock system.

As previously discussed, interlock systems can be classified into five categories: (1) ignition interlock system, (2) entertainment interlock system, (3) accelerator pedal interlock system, (4) speed limiting interlock system, and (5) transmission interlock system. All these devices have inherent intrusive characteristics; therefore, it is possible to assess them based on level of intrusiveness to the drivers. These systems can further be classified based on the degree of intrusiveness to driving activity. Ignition interlock systems are considered to be the most intrusive because they prohibit the vehicle from starting before the seat belt is buckled. Transmission, speed limiting and accelerator pedal interlock systems are considered less intrusive because they allow the vehicle to start moving but restrict the driving capabilities (Kidd et al., 2013).

Acceptance of Interlock Systems

The first interlock system (an ignition interlock device) was highly effective in increasing seat belt use above the very low rate at that time. However, the resultant public outcry subsequently led to Congressional action abolishing the mandatory installation of interlock devices in new vehicles. Findings from recent focus group studies of part-time belt users suggest that seat belt use rates have increased dramatically since 1970; however, seat belt ignition interlock systems are still perceived negatively and are not acceptable to most people (Eby et al., 2004; Bentley, Kurrus, & Beuse, 2002). Subsequent research work led to other interlock systems that were highly effective as well as more acceptable to the public.

Effectiveness of interlock systems is closely linked to acceptability, because motorists are inclined to resist technology that they find excessively intrusive. If they avoid using the system through disabling it, or selective purchasing, users can reduce a technology's actual effectiveness to zero, no matter what its potential safety impact might be (Humphrey, 2003).

In order to understand the acceptance level of various types of interlock systems, a telephone survey was conducted by IIHS. Interviews were done in three sampling phases; 1,200 interviews were completed after filtering participants from the initial 59,000 respondents. Full interviews were conducted only if the respondents indicated they rode in a vehicle either as a driver or passenger once a week and were 18 or older. In the interview, people who were classified as part-time belt users and non-users were asked questions about their attitudes towards seat belts, methods of increasing belt use and in-vehicle seat belt interlock technologies. The survey used questions about attitudes from the 2007 Motor Vehicle Occupant Safety Survey (Boyle & Lampkin, 2008), which included specific questions for non-users of seat belts. The survey showed that less than half of all full-time belt users and less than 30 percent of part-time belt users and non-users would support using ignition interlocks to increase driver belt use. Less intrusive interlock systems like speed interlock, entertainment interlock, or transmission interlock were opposed by 44- to 47 percent of full-time belt users, 59- to 63 percent of part-time belt users, and 75- to 84 percent of non-users. Though levels of support for interlock technology varied among different classes of users, most respondents agreed that the system is helpful in motivating them to use the seat belt.

The acceptability levels for each of the interlock systems is related to intrusiveness; the more intrusive the technology, the less acceptable it will be (Humphrey, 2003). Less intrusive technologies like gear shift delay (33%) and accelerator interlock systems (32%) are more acceptable among the public than more intrusive systems like ignition (30%), speed (30%) and entertainment interlock systems (30%).

In general, most previous research focused on ignition interlocks, gear shift delay interlocks and accelerator pedal interlocks. Very little relevant literature could be found on speed limiting and entertainment interlock systems. Seat belt use and reaction to interlock technologies are related to driver age, gender, and usage style (full-time, part-time, non-use). Rather than demographics, the likely influence on the acceptance and effectiveness of interlock technologies are the attitudes and beliefs that vehicle occupants have towards seat belts and the technologies designed to increase their usage. More studies need to be conducted on measures of relevant attitudes and beliefs to support the interpretation of individual differences in system acceptance.

During this project, UMTRI contacted 20 vehicle OEMs and suppliers to identify those currently involved or interested in the development of seat belt interlock prototypes and technologies. The goal was to obtain information about existing prototype systems; to assess their interest in participating in a field test; and to establish collaboration for leasing test vehicles. Of those contacted, two OEMs responded with two mature prototype systems that could be used in field testing, a transmission interlock system and a speed limiting system.

4. Methodology

To achieve the study goals, a field operational test was conducted to collect both objective data (system effectiveness and driver behavior) and subjective data (user acceptance and satisfaction levels). Two participating OEMs supplied vehicles equipped with prototype SBAS systems. UMTRI fitted them with additional instrumentation to serve as research vehicles. These vehicles were provided to drivers for daily use as their personal vehicles. Driving behavior and interactions with each SBAS were video- and audio-recorded over a three-week period. Institutional Review Board (IRB) approval was obtained from the University of Michigan's IRB office to perform human subjects testing prior to data collection.

Experimental Design

One important consideration for this study was to ensure that the sample of participants was both appropriately selected to address the specific research questions, and of sufficient size to permit adequate statistical power. It was thus critical to include both seat belt non-users, and part-time seat belt users. Both groups comprise the target users for this technology.

The study employed a mixed design in which 48 participants drove for three weeks. Half the participants were randomly assigned to the speed limiter group and the other half placed in the transmission interlock group. A prior power analysis confirmed that the design would have reasonable statistical power.

In the study each participant was given one type of research vehicle for up to three weeks; the first week was used as a baseline with the SBAS was not turned on; the two following weeks served as treatment weeks with the SBAS activated. Seat belt use was recorded and compared across the two driver-groups. The activation of the interlock systems in the test vehicles was directly controlled in the test, to permit baseline measures of non-interlock seat belt use to be compared to conditions in which the interlock was active.

Driver Recruitment

Drivers were recruited through several channels. The University of Michigan has a website used for recruiting volunteers for a wide range of studies. The pool of volunteers includes approximately 30,000 people who have registered their interest in participating in research. A recruitment advertisement for this seat belt interlock study was placed on that site.

Additionally, advertisements were posted on Craigslist, and printed flyers were posted in local coffee shops, cafes, and university bulletin boards. Finally, post cards were distributed at tailgate parties at one U-M home football game. More than 2,900 drivers were screened via telephone concerning their seat belt use for possible participation in this study (see Appendix B for the screening questionnaire). Individuals who passed this initial telephone screening, based primarily on the self-report of at least occasional unbelted driving, were asked for their permission to allow UMTRI researchers to review their publicly available driving record to confirm their self-reported driving history. Prospective participants having any felony motor vehicle convictions, such as driving while intoxicated or under the influence of alcohol, within 24 months of recruitment, were excluded from the study.

Eighty-four self-identified part-time seat belt users participated in this study. The first week (i.e., baseline) of driving data from the 84 participants was reviewed to determine eligibility for the following two-week treatment period of driving. To be eligible, the driving data had to confirm part-time seat belt use. Of the 84 drivers who participated, data from 48 part-time seat belt users was included in the final analyses. Selected drivers were 19 to 60 years old with a mean age of 33. Because of the difficulty associated with recruiting part-time seat belt users, no attempt was made to balance male and female participants.

Driver Orientation and Instruction

Participants came to UMTRI where they were given some details of their participation and completed Informed Consent documents with a researcher. After they enrolled, driver orientation began with an introduction to the research vehicle. Participants where shown the location of standard controls and displays on the research vehicle as well as the location of the video cameras. Drivers were told to drive the research vehicles as they would normally drive their own vehicles. Drivers returned to UMTRI one week later with the vehicles. This constituted the baseline period of data collection for each driver. At the end of the baseline period, video data and vehicle dynamics data were reviewed to determine the amount of unbelted driving by the participant over the time they had the vehicle. If a driver qualified to continue after the first week of participation based upon the percentage of time that they drove the research vehicle while not wearing a seat belt, a researcher instructed the driver about the use of specific, advanced, in-vehicle technologies as a ruse to explain the need for this mid-participation visit and the reason for the accompanied test drive.

In the vehicles with the transmission interlock system, drivers received instruction about the use of an in-vehicle communication system, which was a feature on the research vehicle. Further, they learned that the research vehicle could not be shifted out of park if the driver and/or the front seat passenger was not wearing a seat belt.

In the vehicles with the speed limiter system, drivers were instructed about the use of the navigation system. They were asked to enter an address provided by the researcher, then drive to that address (a location close to UMTRI). During the drive, the researcher explained and then demonstrated that they would be unable to drive faster than 15 mph if they or their front seat passenger was not wearing a seat belt. On the test drive, the driver also observed the warning and deceleration produced if the seat belt was released while driving. Finally, use of an override (to release the speed limiter) was demonstrated to avoid placing the driver in dangerous situations.

At no point were drivers told that this study investigated seat belt interlock systems or seat belt use in general in order to avoid alerting them to the study’s objectives and influencing their behavior. Drivers returned for the final visit to UMTRI two weeks later to return the vehicles and complete questionnaires. This constituted the Treatment Period.

Post-Drive Questionnaire

At the conclusion of the three weeks of driving, participants completed the post-drive questionnaire (Appendix C).

Vehicles and Instrumentation

Two types of research vehicles with distinct SBASs were used in this study, transmission interlock systems, and speed limiter systems.

Transmission interlock system

The transmission interlock system prevented a vehicle that had just had its ignition turned on from being shifted into gear if either the driver or front seat passenger was unbelted. Sensors used in this technology detected the status of the transmission, seat belt buckle state ("buckled" or "unbuckled" on both the driver and the front seat passenger side), and brake pedal status. The seat belt status of rear passengers was disregarded by the system.

The standard (or enhanced) seat belt reminder (SBR) in these vehicles (baseline condition for this vehicle) had both visual and audio warnings. The SBR was triggered by either an unbelted driver or an unbelted front seat passenger.

During the treatment period, in addition to the SBR visual telltale and audio messages, additional visual and audible message were presented to drivers by the interlock system. If the driver and/or the front seat passenger was not belted, the vehicle was in park, and the brake was applied to shift into drive, a visual and audible message was presented indicating that that shifter was locked and the seat belt must be buckled to shift into gear. While the messages from the interlock system were being presented, the SBR visual and audio messages were also active. The shifter automatically unlocked after 30 seconds, although drivers were not specifically made aware of this.

Speed limiter system

The speed limiter system allowed limited vehicle function, but limited vehicle speed when detecting an unbelted driver or unbelted front-seat passenger, to speeds below 15 mph. If the system was activated when speeds were above 15 mph (either the driver or the front-seat passenger removed the seat belt while the vehicle was in motion) the travel speed of the vehicle was reduced to 15 mph automatically at a fixed deceleration rate after a set period of time.

An SBR in these vehicles (baseline condition) was present and has mandatory lamp/buzzer warnings. The SBR messages could also be triggered by either an unbelted driver or an unbelted front-seat passenger. After 6 seconds with the engine on, more aggressive visual and auditory warnings were presented to drivers.

During the treatment period, the system issued a continuous aggressive seat belt reminder. This was an acoustic gong and visual warning explaining the reduced vehicle function in the central display ("Buckle up!"). During this period, an "escape" function was available to override the limiter. This required a full depression of the accelerator pedal to temporarily accelerate the vehicle. Unless the pedal was fully depressed, the vehicle speed would be reduced to 15 mph. Sensors used in the speed limiter system included: seat belt hall sensors (only front seats).

Field Data Collection

Data Collection Instrumentation System

Each vehicle was equipped with an UMTRI data acquisition system (DAS). This system consisted of the following elements.

- Embedded microcontroller board for recording objective data
- Video module for recording the forward scene
- Video module for recording the vehicle cabin (with audio)
- Infrared cabin illumination
- GPS receiver
- CAN bus interface
- Custom power/interface/controller board

A diagram of the system is shown in Figure 1.

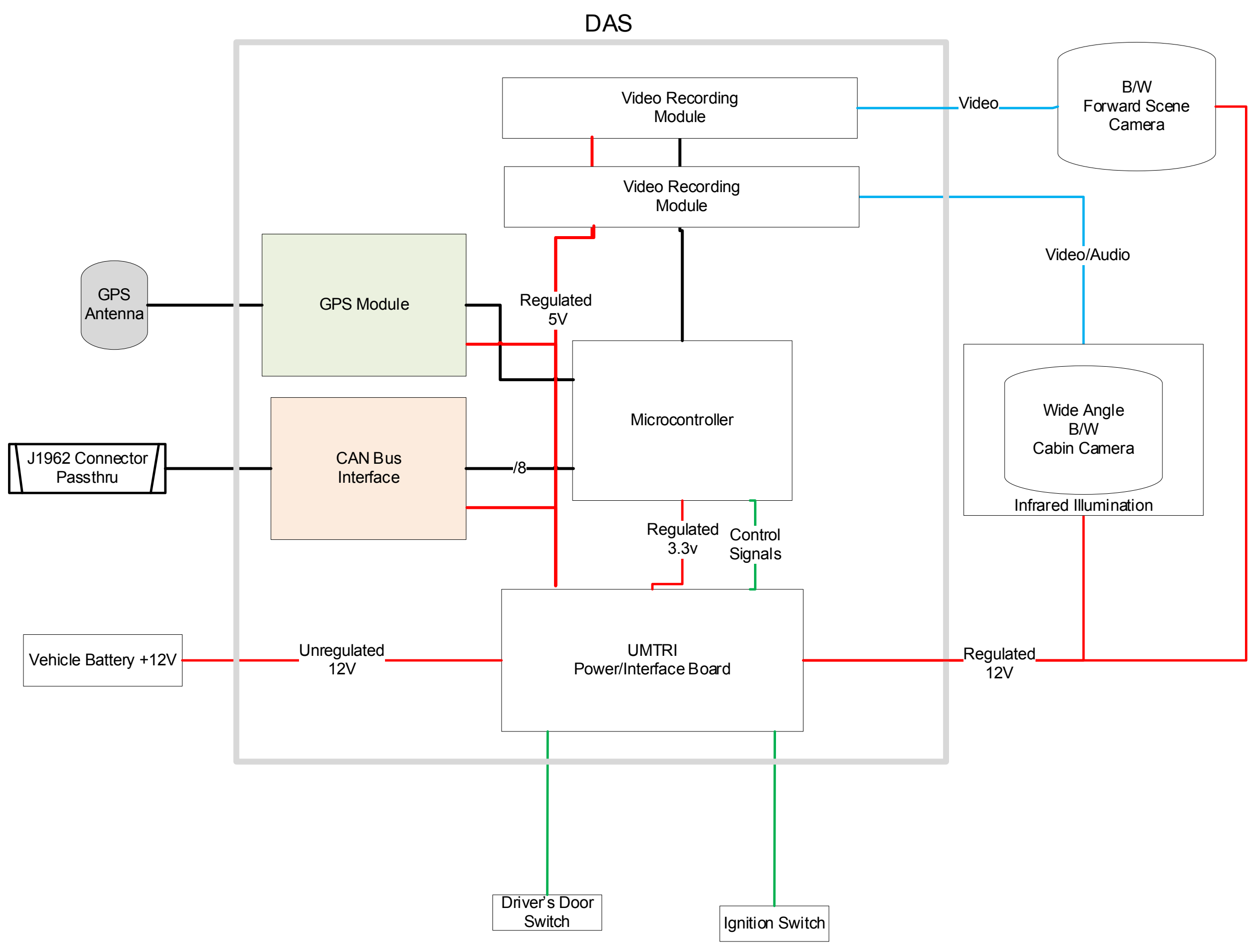

Figure 1. Instrumentation System Components.

UMTRI DAS

All the equipment and wiring was concealed behind trim panels in the vehicle. The system was configured to boot and begin recording when the door was opened or the remote keyless entry fob button was pressed (see Table 1). Data collection began immediately and video capture typically began in 14 seconds. Once the 2-minute timer expired, the microcontroller turned off all peripheral devices and entered a low-power state, to conserve vehicle battery power. The DAS enclosure was roughly the size of a large hardback book, and is shown in Figure 2. In Vehicle A (speed limiter system), the DAS was mounted behind the driver's side rear quarter trim panel. In Vehicle B (transmission interlock system), it was mounted below the package shelf in the trunk.

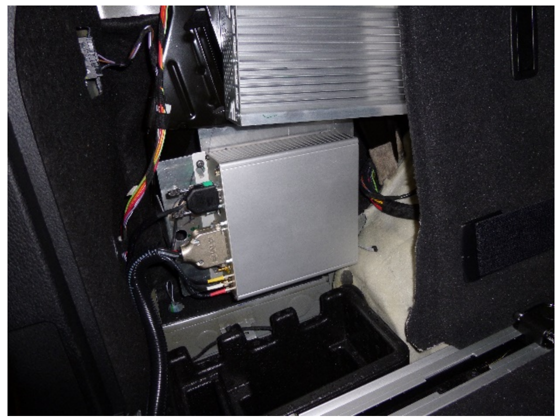

Figure 2. Data Acquisition System Enclosure.

The cabin camera was a black and white unit, small enough to be located behind trim at the base of the passenger side A-pillar. Small fascias were 3D printed to provide a finished appearance. Since the trim piece had to be modified, replacement parts were ordered and used to restore the vehicle to its original condition at the end of the study. The cabin camera can be seen below in Figure 3. A still frame of the recorded video from the camera mounted at the base of the passenger side A-pillar is shown in Figure 4.

Cabin Camera, Vehicle A

Cabin Camera, Vehicle B

Figure 3. Cabin Camera Locations.

Figure 4. Sample Video From the DAS Camera.

On both types of vehicles, the forward scene camera was mounted to the windshield directly in front of the rear-view mirror, to the right of the mirror mount. The microphone was mounted to the side of the camera bracket.

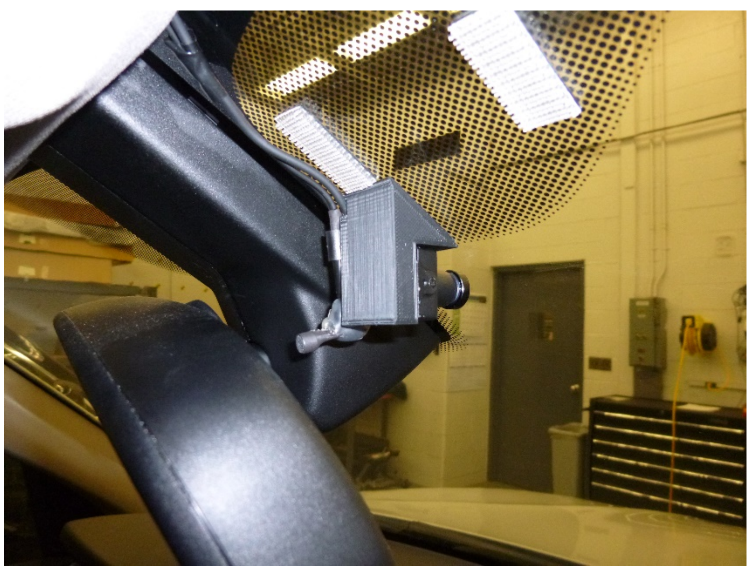
Figure 5. Forward Scene Camera and Microphone.

Infrared illumination was integrated into the vehicle's dome lamp assemblies. It was powered at all times when the DAS was collecting data.

The GPS antenna used was an interior glass mount unit. On Vehicle A, it was mounted at the base of the windshield on the passenger side. On Vehicle B, it was mounted at the top of the rear window on the passenger side. Vehicle A's installation is pictured in Figure 6.

Figure 6. GPS Antenna.

Data Channels

In addition to the GPS data, the two vehicle platforms had similar, but not identical, channels that were monitored. A list of all the data channels is shown in Table 1 below.

Table 1. Data Channels Collected on Both Vehicle Types.
System A refers to the speed limiter system while System B refers to the transmission interlock system.

	System A	System B
Digital Inputs		
	Vehicle Wake	
	Ignition	Ignition
		Dome Lamp
CAN Bus Inputs		
	Driver Belt	Driver Belt
	Passenger Belt	Passenger Belt
	Passenger Present	Passenger Present
	Driver Door	
	SpeedLimitActive	
		Unlock
		Shifter Lock Request
		BrakeToShiftIndication
		ShifterLockIndication
		VehicleInDriveGear
	CabinVideoPowerOn	CabinVideoPowerOn
	ForwardVideoPowerOn	ForwardVideoPowerOn
	CabinVideoRecording	CabinVideoRecording
	ForwardVideoRecording	ForwardVideoRecording
GPS Inputs		
	GpsTime	GpsTime
	Latitude	Latitude
	Longitude	Longitude
	Height	Height
	Speed	Speed
	Heading	Heading
	HorizontalAccEst	HorizontalAccEst
	SpeedAccEst	SpeedAccEst

Both video and objective data were stored on microSD memory cards. At the end of each participants' exposure period, when each vehicle was returned to UMTRI, the cards were removed and the raw data was transferred to an UMTRI file server. The raw data was then parsed and loaded to an SQL database, where the data were reviewed and processed before analysis.

Data Reduction

The SQL server database allowed events (e.g., a seat belt being unlatched while the vehicle is traveling more than 50 mph) to be quickly identified using queries. Video and other data around those events could then be reviewed using a custom application to review the data sources (video and data) synchronized in time. SQL procedures generated tables of events for each participant's data. Databases containing information about drivers' belt use rate and behavior during each trip (with or without the SBASs) were created for further analysis. Comprehensive review of the video data was performed to identify any methods used to defeat the SBASs, and assessment of the degree of difficulty required to do each.

Both qualitative and quantitative analysis were conducted for the purpose of this study. Descriptive analyses include belt use rate with different SBAS-equipped vehicles for different driver populations.

Data Format

For this data set a "trip" was defined as one recording cycle for the DAS. A DAS recording cycle would start when the DAS received one of a large number of signals that included activities such as the car being started, key fob activation or a door being opened (based on the dome light.) A DAS recording cycle ended when no signals were received after a set length of time (2 minutes). The parameters were established to ensure data was collected during any relevant time (such as belting in the vehicle before ignition) but that the DAS would also stop recording after a reasonable time interval in order to preserve the vehicle's battery power.

A "trip" then in this case could include multiple ignition cycles, multiple entries and egresses from the vehicle and multiple destinations. Based on this methodology, many "trips" were discarded as invalid because nothing happened in the vehicle. Often a fob was activated and no one entered the car, so the DAS would simply time out. These empty "trips" had durations of approximately 2 minutes and 10 seconds. Any other activity in the vehicle would extend the DAS cycle and thus the trip duration.

Classification of Belted and Unbelted Events

During data quality checks, it was found that occasionally the seat belt flags in the data stream on the DAS were reported as NULL (versus "1" for belted and "0" for unbelted). To determine the source of the NULL values in the data, technicians ran in-depth analyses of both vehicle platforms. Based on several factors including the boot-up timing of the DAS and the vehicle CAN-busses, the ignition state and the inter-trip time (for DAS shutdown.) thirty-nine unique sequences were identified that could produce NULL values obscuring the seat belt status flag. The different sequences could involve quick ignition cycles or long periods of time when the participant was simply sitting in the car, belting and unbelting. Unexpected sequences of events such as these could result in the belt flag returning these NULL values. Once the scenarios that would produce these NULL values were identified, the data could be corrected systematically to restore the belt flag to its correct value.

Many of these scenarios were fixed with large-scale updates where a consistent fix was applicable across the entire scenario, however for some scenarios there was no quantitative method for correcting the data and the seat belt state had to be visually identified and updated.

Classification of "Moving Events"

Measured GPS speed was used in the objective dataset to determine if the vehicle was in motion. During pilot testing, this proved to be a reliable measure. However, during the study, it was found that under some conditions the GPS receiver (uBlox 6P) would report the vehicle to be in motion when in fact it was not. These conditions were primarily associated with poor sky view, such as parking beneath dense tree cover, between multistory buildings, or in a parking garage. Other causes included snow over the antenna, and a loose connector between the antenna and the receiver. To remedy this issue, midway through the study the GPS receiver modules were replaced with a more current unit, the uBlox M8U. This newer device had more sensitivity than the older receiver, supported both GPS and GLONASS constellations, and incorporated inertial sensor-based dead reckoning. Data collected with this receiver reported the vehicle motion reliably.

Data analysis strategies were employed to determine if the vehicle was in motion or not for datasets collected with the uBlox 6P. These included:

- Incorporating the quality metric output by the receiver,
- Tuning the speed threshold below which the vehicle was classified as stopped, and
- Classifying the vehicle as stopped whenever it was not in a drive gear (transmission interlock vehicles only).

These strategies still left a significant number of events in which vehicles were improperly classified as moving when they were stationary. To resolve this issue, the forward video was processed and analyzed to determine vehicle motion using an optical flow metric. The algorithm was developed and calibrated using trips that employed the more reliable GPS receiver data (uBlox M8U). Then all trips where the GPS data was in question had their forward video processed and analyzed. These results were then loaded in the SQL database and synchronized with the other objective data to provide a single common measure of vehicle moving/stopped.

Two examples below (Figures 7 and 8) show visualizations of the difference in optical flow between a vehicle that was stopped and one that was in motion. As shown in both figures, moving objects generated brighter patterns, while stationary vehicles generated darker images. The differences in brightness were important to distinguish moving vehicles from stationary vehicles. These visualizations were produced using Simulink. After the algorithm development was complete in Simulink, it was ported over to run in Matlab code, which was much more efficient. The output of the analysis was a metric of net optical flow. Criteria were then established to classify the vehicle as being in motion or stopped based on that net optical flow. This optical flow method kept a significant portion of the dataset from being excluded from analysis.

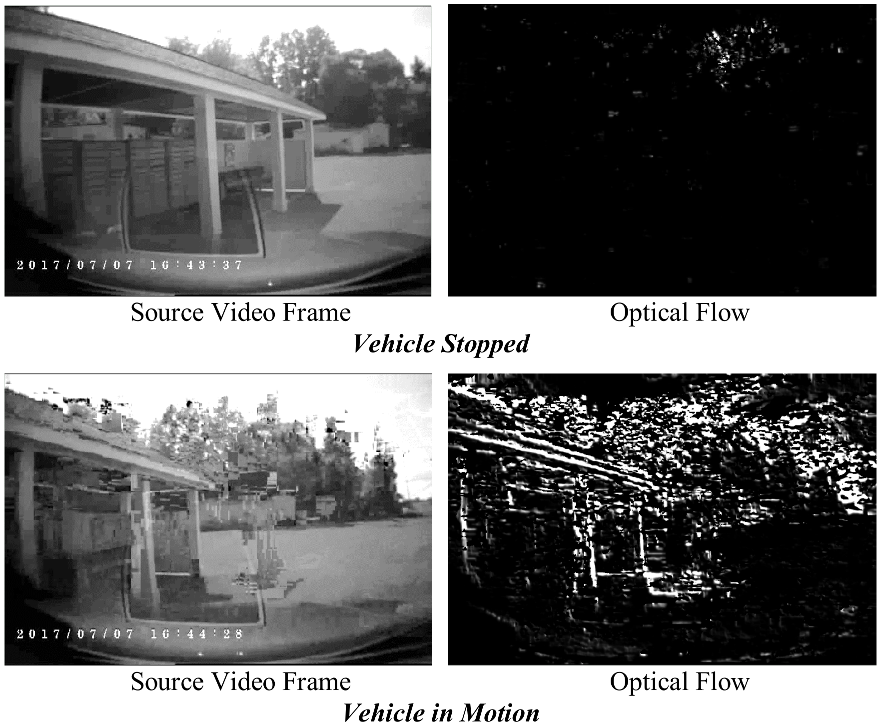

Figure 7. Comparison of Stopped/Moving Optical Flow.

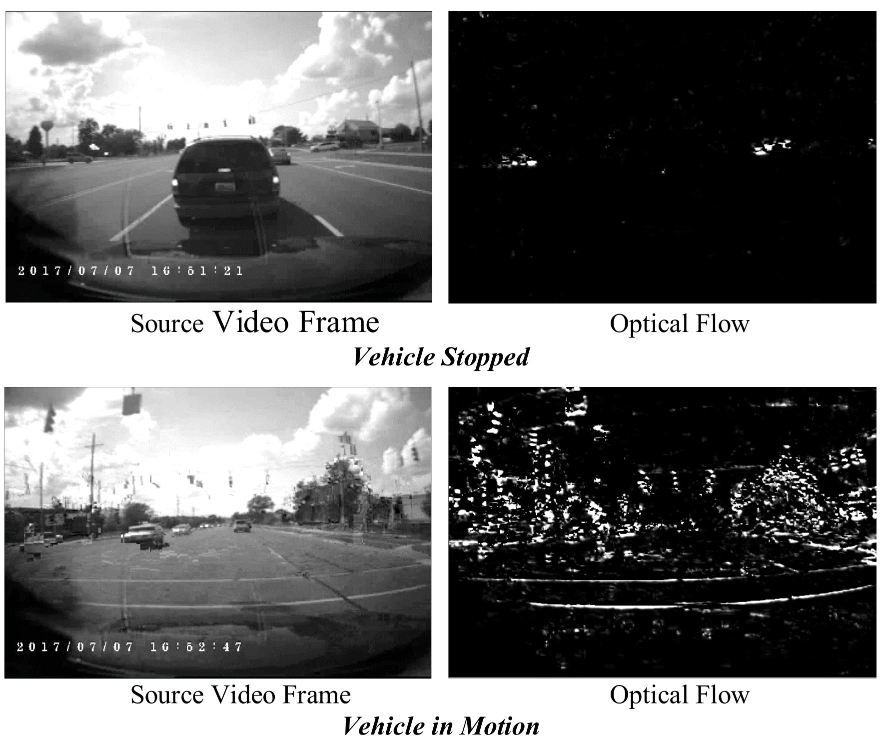

Figure 8. Comparison of Stopped/Moving Optical Flow.

5. System Effectiveness Results

The 48 drivers were divided into two groups based on the frequency with which they were seen driving unbelted in the baseline period. Half (24) the participants were classified as "Frequent Seat Belt Users" while the other half were classified as "Infrequent Seat Belt Users." This distinction was specifically based on whether their percentage of unbelted driving time was greater than ten percent of their total driving time.

The full data set contains 11,086 DAS cycles which were recorded from the 48 drivers over the three-week participation period. A total of 6,254 valid trips were identified and included in the final analysis as "Valid Trips." A valid trip was defined based on the requirement that a trip would need to contain at least 5 seconds of actual moving data and was from the participant driver. This 5-second threshold was established to remove trips where no driver entered the vehicle and the data collection was simply triggered by some outside event (e.g., DAS was triggered by key fobs use). By definition, valid trips all had durations longer than 2 minutes 10 seconds, as a function of the data acquisition system time-out.

Table 2 shows the final dataset contains 1,785.6 hours of video data with the average amount of driving data collected per driver per day at about 1.77 hours.

Table 2. Distribution of Data Collected in Trips and Hours for Each SBAS Group.

SBAS	Treatment	Belt-user group	# of valid trips	Driving hours	# of participants
Speed Limiter System	Baseline	Frequent-belt user	757	234.82	15 (6 male, 9 female)
Speed Limiter System	Baseline	Infrequent-belt user	554	178.00	12 (6 male, 6 female)
Speed Limiter System	Treatment	Frequent-belt user	1323	382.85	
Speed Limiter System	Treatment	Infrequent-belt user	858	283.83	
Transmission Interlock System	Baseline	Frequent-belt user	497	124.71	9 (5 male, 4 female)
Transmission Interlock System	Baseline	Infrequent-belt user	573	159.05	12 (5 male, 7 female)
Transmission Interlock System	Treatment	Frequent-belt user	676	136.36	
Transmission Interlock System	Treatment	Infrequent-belt user	1015	285.98	

As explained in the previous section, one of the recruitment requirements was that only part-time seat belt users should be considered for this study. Therefore, even though all the participants were equally and randomly assigned to one of the two SBAS groups at the start of their participation, the final number of participants qualifying to complete the three-week data collection for the two SBAS groups were not balanced. As a result, 27 drivers received the speed limiter system while twenty-one received the transmission interlock system (Table 2). The final set of participants included 22 men and 26 women. The unbelted rate was calculated through two methods, the percentage of time moving while unbelted and the percentage of trips with unbelted driving.

Percent of Time Moving While Unbelted

Of interest was the frequency with which participants drove while unbelted during both the baseline period and the treatment period. This was calculated as the percentage of unbelted driving time. A general linear mixed model was conducted to examine whether and how a series of explanatory factors impacted the unbelted rates.

The explanatory factors that were included in the mixed-models included three between-group and one within-group variables. The between-group variables:

1) Age group ("younger": 35 or younger; "middle-aged": 36 or older)
2) Gender (male or female)
3) SBAS group (speed limiter system or transmission interlock system)
4) Belt-user group (frequent or infrequent seat belt users)

The one within-group variable was the treatment condition (baseline or treatment period). Interaction terms between each of the two factors were also included. The general linear mixed model was conducted in SAS by using the "Proc Mixed" procedure.

Treatment condition and belt-user group

Results showed a significant main effect of treatment condition. The percentage of unbelted driving time significantly decreased during the treatment period as compared to the baseline period ($F(1,44)=30.94$, $p<0.01$). Overall, drivers were unbelted in the baseline period an average of 24.1 percent of the driving time. There was a significant reduction in the percentage of unbelted driving time during treatment period, with the average percentage decreasing to 10.7 percent.

The impact of belt-user group was also found to be significant ($F(1,42)=30.89$, $p<0.01$). On average, infrequent belt users had a significantly higher unbelted rate (least square means of 32.9%), when compared to the frequent belt users at 2.9 percent.

The interaction effect between treatment and belt-user group was significant ($F(1,44)=19.9$, $p<0.01$). As Figure 9 below shows, the percentage of unbelted driving time for infrequent belt users during the treatment period significantly decreased from baseline driving (differences in least square means: $\Delta=25.9$ percent, Confidence Interval: CI (18.7%, 33.2%), $p<0.01$). On the contrary, the differences for frequent belt users between two treatment conditions was very small ($\Delta=2.9$ percent, CI (-4.6%, 10.4%), $p=0.44$) and can be ignored.

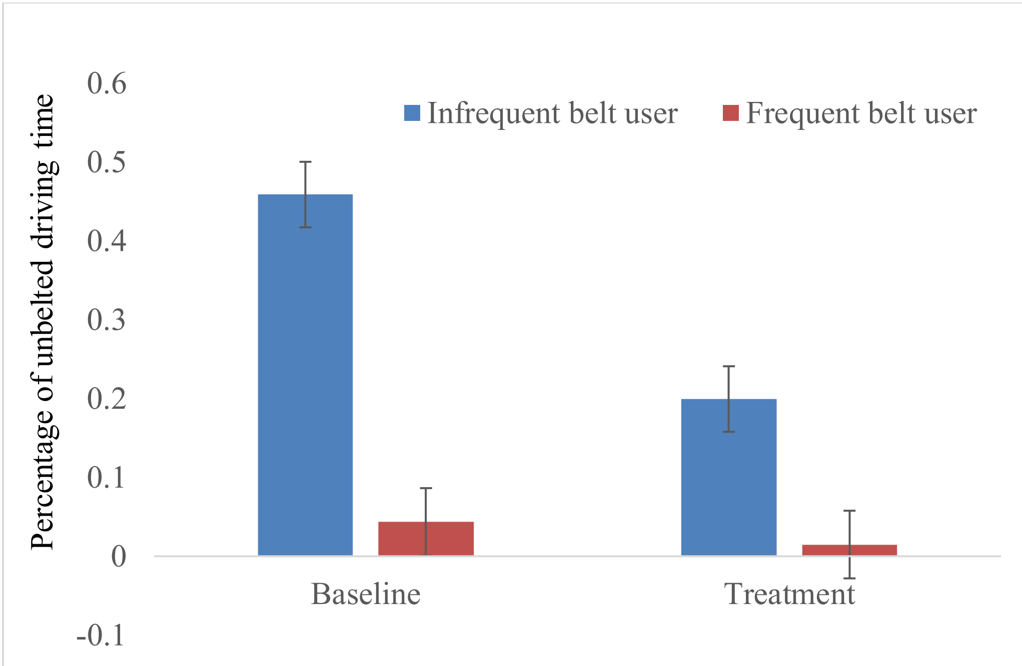

Figure 9. Percentages of Unbelted Driving Time Between Two Belt-User Groups During Treatment and Baseline Driving.

SBAS type

No main effect of SBAS type was observed ($p>0.05$). A similar percentage of unbelted driving time was observed for drivers between the speed limiter group (16.5%) and the transmission interlock group (19.4%).

The interaction effect between SBAS type and treatment condition was not statistically significant ($p>0.05$) either. The reduction in the percentage of unbelted driving time from baseline to treatment periods were significant for both speed limiter (Δ=13.3%, CI (6.4%, 20.2%), $p<0.01$) and transmission interlock systems (Δ=15.5%, CI (7.7%, 23.4%), $p<0.01$). The percentage of unbelted driving time for each vehicle platform during both treatment phases is displayed in Figure 10.

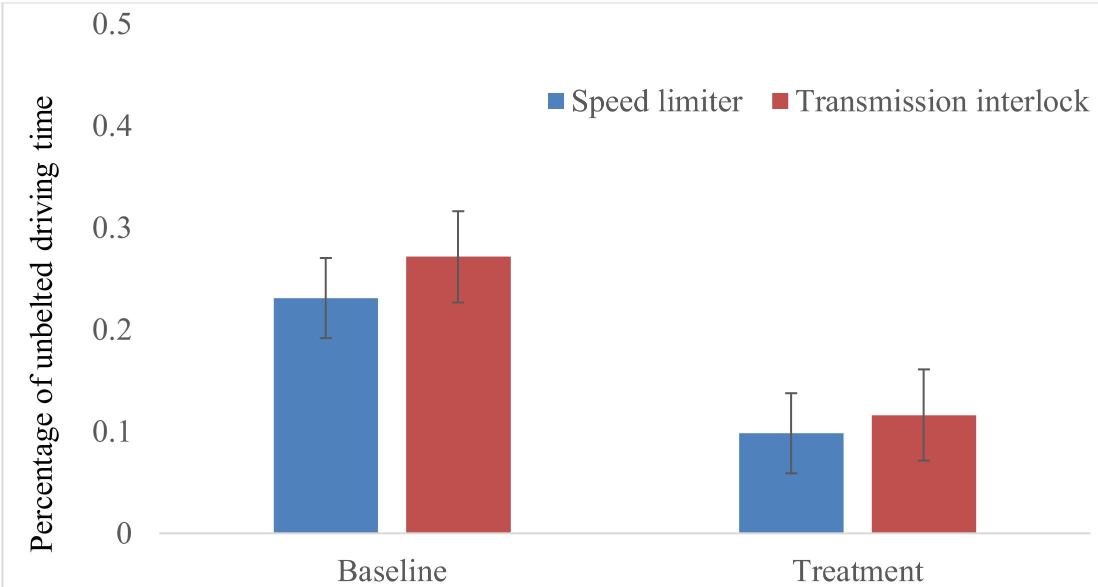

Figure 10. Percentages of Unbelted Driving Time for Both SBAS Types During Baseline and Treatment Driving.

Age and gender

No age group or gender related differences were found to be statistically significant ($p>0.05$). Younger and middle-aged drivers showed a similar average of the percentage of unbelted driving time (18.9% for younger drivers; 16.9%for middle-aged drivers) and a similar percentage decrease from the baseline to the treatment period. Similar results were found for the two gender groups (13.8% for female drivers; 21.9%for male drivers). Males were slightly, but not significantly more likely than females to be unbuckled during both baseline and treatment periods.

Individual drivers

Figure 11 depicts the percentage of unbelted time for each individual driver. The participant with the largest percentage of unbelted driving time in the baseline period did not use the seat belt for over 99.6 percent of the total driving time (while the vehicle was in motion), with the percentage of unbelted time for this participant staying high at 93.6 percent during the treatment period. The lowest unbelted time percentage was about 0.2 percent.

Nine drivers were seen driving while unbelted for more than 50 percent of their driving time during the baseline period (4 participants from the speed limiter group and 5 from transmission interlock group) while the number decreased to 3 drivers during treatment condition (1 from the speed limiter group, 2 from transmission interlock group).

Interestingly, 6 participants' unbelted moving time percentage increased during the treatment period when compared to the baseline period, while the percentage of the other 42 drivers all decreased as expected.

Of the 6 drivers whose percentage of unbelted moving time increased in the treatment period (5 participants from the speed limiter group and 1 from transmission interlock group), 5 had negligible increases (3% or less) while one had an increase of 25 percent. The driver showing the largest increase was also observed "cheating" the SBAS system often during the treatment period.

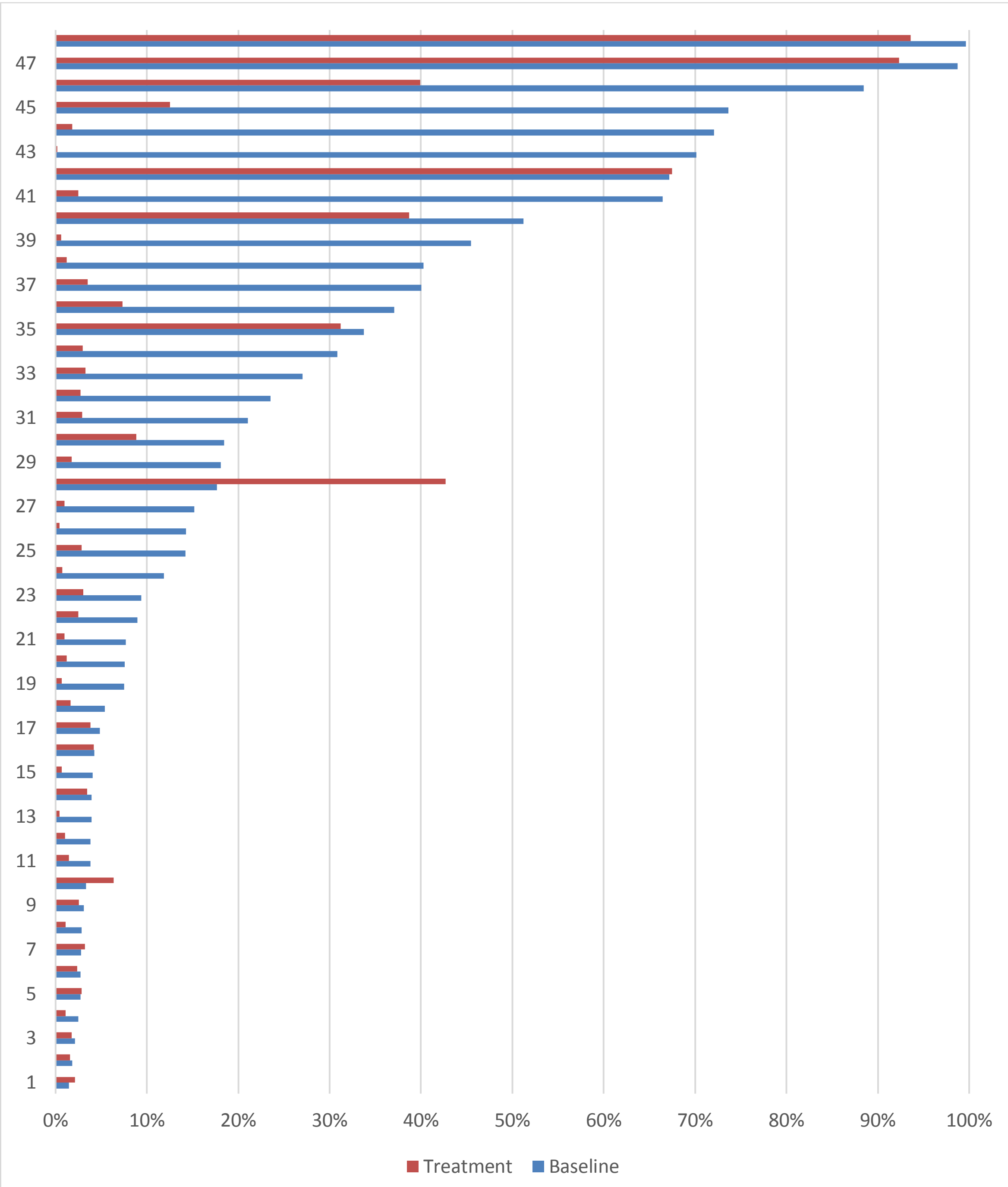

Figure 11. Percentage of Unbelted Driving Time by Driver.

Percentage of Trips With Unbelted Driving

The percentage of unbelted trips was also calculated for each driver during both the baseline and treatment periods and examined by using general linear mixed models ("Proc Mixed" procedure in SAS). Independent variables included age group, gender, SBAS group, and belt-user group (frequent or infrequent belt users). Driving hours was also included in the model as a covariate. Six drivers were observed driving unbelted for at least some portion of all of their driving trips. All 48 drivers had some trips with some unbelted driving during both the baseline and treatment period.

Significant main effects of treatment conditions ($F(1,54)=25.2$, $p<0.05$), SBAS ($F(1,41)=4.8$, $p<0.05$), and belt-user group ($F(1,41)=18.2$, $p<0.05$) and were observed. In general, a significant decrease in the percentage of unbelted trips was also observed during the treatment period (57.8%) compared to the baseline period (77.6%). A significantly lower unbelted trip rate was observed for drivers from the transmission interlock group (62.9%) than for drivers from the speed limiter group (72.6%). A significantly higher unbelted trip rate was observed in infrequent-belt users (77.1%) than in frequent-belt users (58.4%).

Results showed one significant interaction effect of SBAS system by treatment period ($F(1,44) =7.1$, $p<0.05$). As Figure 12 shows, the percentage of unbelted trips for the transmission interlock group during the treatment period was significantly smaller than during the baseline period (Δ=29.5 percent, CI (18.2 percent, 40.7%), $p<0.01$). The percentage reduction for the speed limiter group drivers between the two treatment conditions was smaller but also significant (Δ=10.1 percent, CI (0.01 percent, 20.4%), $p=0.05$).

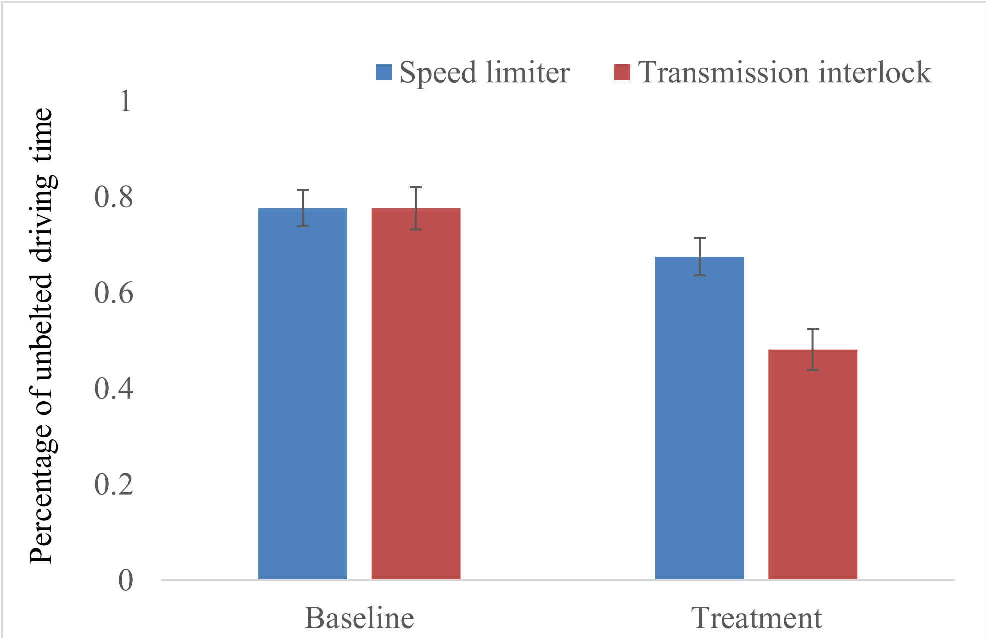

Figure 12. Percentage of Unbelted Trips for Two SBAS Groups During Baseline and Treatment Driving.

6. System Defeating and Unexpected Consequences Identification

The ways in which participants may defeat or "cheat" the SBAS in order to drive without properly wearing their seat belts was one of the main interests of this study. UMTRI researchers first reviewed video clips from all of the valid driving trips to confirm the correct (i.e., enrolled participant) driver was driving. Any instances of system cheating that were observed during this review were noted. After the first review, any driver who was previously seen with any cheating behaviors had all of thedriver's trips re-reviewed for a second time more thoroughly to determine the exact type of cheating behavior involved and whether encompassed the whole trip or only a portion of the trip. Nine individual drivers were identified who showed some kind of "cheating" behavior. Eight of these drivers cheated the SBAS during the treatment period driving, while 3 drivers tricked the SBRS during baseline period driving (Table 3). Drivers were motivated to trick the system while in the baseline condition to suppress the reminder tones. The 3 drivers observed tricking the system in the baseline condition all simply buckled the seat belt behind them and left it buckled for multiple trips.

Of those 8 drivers who tricked the SBAS (during treatment driving) by not using the seat belts appropriately, 5 were from the transmission interlock group (23.8% of the drivers from that group) and the remaining 3 were from the speed limiter group (11.1% of the drivers from that group).

Two main defeating methods were observed with the most common method being buckling the belt before entering the vehicle and then sitting on the lap belt (example shown in Figure 13). Cases when the participants pulled the shoulder strap over themselves while driving but continued to sit on the lap belt were also considered as cheating. This method was observed in both SBAS groups. The other method of cheating only took place with the transmission interlock system. In this system, the SBAS is automatically dismissed 30 seconds after the ignition is turned on, even if the driver has not put on a seat belt. Drivers who cheated in this way, (either purposefully or by accident,) would wait out the interlock timer and could then drive unbelted in both the baseline and the treatment period. In this study, all events using the two methods were identified as "cheating behavior" and used in the analysis. It is worth noting that drivers may not be aware of their own cheating behavior by accidently waiting out the transmission interlock timer during treatment period driving. However, the safety consequences of such behavior (not using the seat belt appropriately) whether on purpose or not would be the same.

Table 3. Cheating Frequency by Driver.

				Baseline			Treatment		
Participant ID	Age	Gender	SBAS	Valid Trips	Trips with Cheating	Unbelted Time	Valid Trips	Trips with Cheating	Unbelted Time
109	M	M	Transmission	34	0	67.20%	52	52	67.40%
125	Y	M	Transmission	52	0	51.20%	72	64	38.70%
153	M	M	Speed Limiter	36	0	17.70%	58	37	42.70%
163	Y	M	Speed Limiter	36	36	99.60%	44	44	93.60%
165	M	F	Speed Limiter	50	21	40.00%	84	0	3.50%
166	Y	M	Transmission	58	0	88.50%	133	101	39.90%
172	M	F	Transmission	57	0	98.70%	113	111	92.30%
174	Y	F	Speed Limiter	63	14	33.70%	81	65	31.20%
177	Y	F	Transmission	58	0	37.10%	108	2	7.30%

Figure 13. One Example of Pre-buckling Cheating Behavior.

A short description of each participant's cheating behavior is summarized in Table 4. During the baseline driving period, three participants were observed to be cheating to avoid the SBRS by pre-bucking and sitting on the seat belts. During the treatment period, eight participants were observed to have one of the two cheating behaviors. All four speed limiter group drivers and two transmission interlock group drivers cheated by pre-buckling their seat belt behind them before entering the vehicle and left it that way for many trips consecutively. Two drivers from the transmission interlock group waited out the interlock timer and were able to drive the vehicle while unbelted without the intervention from the interlock system. Interestingly, one driver from the speed limiter group who has an average of 34.0 percent of unbelted driving time showed frequent cheating behavior during baseline, but no cheating behavior was observed for this participant during treatment driving.

Overall, 8 of 48 (16.7%) drivers were observed to cheat the SBAS during some or all of their trips. The trips with observed cheating comprised 7.6 percent of all trips across the 48 participants. Odds ratio was calculated to assess the likelihood of cheating associated with SBAS type and treatment condition. Drivers from the transmission interlock group are about 2.5 times (odds ratio =2.5) more likely to cheat than the drivers from the speed limiter group while drivers were 3 times (odds ratio =3) more likely to not use seat belt in the correct way during treatment condition than during baseline condition.

Table 4. Description of Cheating Behavior for all Cheating Drivers.

SBAS	Participant	Baseline (SBRS)	Treatment (SBAS)
Transmission	109	No cheating observed. Often unbelted and sometimes buckle up during highway driving	Cheating behavior observed by waiting out interlock timer on every trip
Speed limiter	163	Cheating behavior observed with pre-buckling and sitting on the seat belts	Cheating behavior observed with pre-buckling and sitting on the seat belts
Transmission	172	No cheating observed and the driver ignored chime on all trips	Cheating behavior observed with pre-buckling and sitting on the seat belts
Transmission	125	No cheating observed with many unbelted and partially unbelted trips	Cheating behavior observed with pre-buckling and sitting on the seat belts
Speed limiter	174	Cheating behavior observed by pre-buckling and sitting on the seat belts	Cheating behavior observed with pre-buckling and sitting on the seat belts
Transmission	166	No cheating observed while responds to SBRS chime	Cheating behavior observed by waiting out interlock timer on every trip
Speed limiter	153	No cheating observed while responds to SBRS chime	Cheating behavior observed with pre-buckling and sitting on the seat belts
Transmission	177	No cheating observed Some unbelted driving at beginning/end of trips	Cheating behavior observed with pre-buckling and sitting on the seat belts
Speed limiter	165	Cheating behavior observed with pre-buckling and sitting on the seat belts	No cheating

7. User Acceptance

User acceptance was examined by analyzing participants' responses to the post-study questionnaires. Appendix C contains a copy of the questionnaire developed to measure drivers' subjective evaluations of the speed limiter system and transmission interlock system. The questionnaire was divided into two parts.

Part A-user rating included fixed choice questions about the perceived usability of the technology. The items were created to measure the three standard components of usability (defined by ISO 9241): effectiveness (perceived benefits from using technology), efficiency (perceived effort to use technology), and satisfaction (emotion reaction and attitude toward technology) (Bevan, 1995). Drivers indicated their level of agreement to individual statements that reflected each component of usability (Disagree strongly, Disagree, Not sure, Agree, Agree Strongly). Ratings were scored on a 5-point scale with 5 representing greatest agreement. The data for Part A were examined using Boxplots. A summary explanation of Boxplots is provided in Appendix C.

Part A-individual user experiences contained open-ended questions to assess driver experience as users of the technology in terms of

1) Most liked aspect of the technology,
2) Most disliked aspect of the technology,
3) Most frustrating experience with the technology, and
4) Recommended changes to the technology.

Responses from Part A-individual user experiences were examined qualitatively by summarizing common themes and listing example statements.

Part A-User Rating

An exploratory analysis was conducted to determine if the pattern of responses matched the conceptual three-factor structure of the survey (effectiveness, efficiency, satisfaction). Instead, principle component analysis (PCA) indicated that response variability reflected two substantive and meaningful factors. Table 5 shows the loadings of items on these two factors after removing items that loaded on both factors or had low factor loadings (< 0.50). The interpretation of these remaining items suggests that responses were primarily related to (1) benefits of using the technology, including resulting attitudes toward the technology, and (2) ease of interaction with the technology. These two factors overlap with the original concepts of effectiveness and efficiency. Apparently, the original satisfaction concept was perceived by drivers to relate with perceived benefits.

Table 5. Factor Loadings of Questionnaire Items Measuring Perceived Effectiveness and Efficiency.

Item (NOTE: Items 5, 10, 14, 17, 18, & 20 removed with loadings < 0.5 or loading on multiple factors)	**Component** **Benefit**	**Usability**
Q1 Helps me enjoy driving.	0.85	
Q1 Helps me get to my destination.	0.85	
Q3 Helps me avoid traffic hazards.	0.76	
Q4 Prevents crashes.	0.77	
Q6 Benefits my passengers.	0.65	
Q7 Benefits me as a driver.	0.78	
Q8 Makes me drive as safe speeds.	0.67	
Q9 Makes me keep a safe following distance	0.71	
Q11 It is easy to learn how to use this technology.		0.78
Q12 This technology is easy to operate.		0.65
Q13 I can always remember how to use this technology.		0.74
Q15 I understand how this technology works.		0.80
Q16 This technology does not require lots of my attention.		0.69
Q19 This technology makes it clear when it is not working properly.	0.53	
Q21 This technology relieves me from demanding that front passengers wear seat belts.	0.60	
Q22 I enjoy this technology.	0.88	
Q23 I trust this technology.	0.65	
Q24 I rely on this technology.	0.73	
Q25 I want this technology in my own car.	0.86	
Q26 I would pay more to have this technology in my next car.	0.74	
Q27 I look forward to using this technology.	0.88	
Q28 I am satisfied with the function/design of this technology.	0.82	
Q29 I am never stressed by this technology.	0.84	
Q30 I think the interface of this technology is clear.	0.63	
Q31 I would recommend this technology to my friends.	0.88	
Q32 I would like this technology to work on my rear seat passengers.	0.62	
Percentage Variance Explained =	**48.16%**	**13.30%**

Extraction Method: Principal Components Analysis, no rotation, minimum factor score = 0.50, forced two-factor solution.

Curiously, the item specific to seat belt use ("Makes me wear my seat belt") did not load on either factor even though the evaluated technology is designed to increase seat belt use. However, this omission seems to be due to the low response variability for this item. As shown in Figure 14, nearly all drivers (86%) agreed strongly that the technology made them wear their seat belts. However, there were several "outliers" that did not agree the technology increased seat belt use.

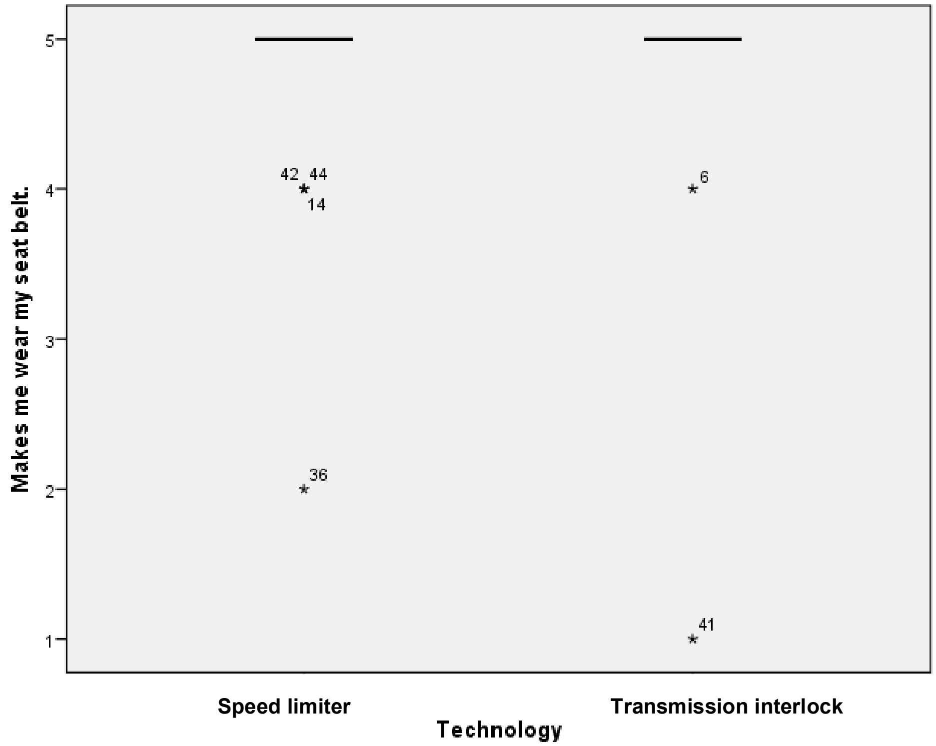

Figure 14. Boxplot of Agreement Ratings That Technology Made Drivers Wear Their Seat Belts.

(Note: Ratings are on a 5-point scale with 5 representing highest level of agreement.)

Given that PCA is based on covariation amongst items, this item would not be expected to load on any factor because it had little variability itself. In addition, Figure 14 also suggests that there were no apparent differences between the technologies in terms of perceived impact on seat belt use.

Based on the remaining items, scores were created using the median rating across all items loading on each factor (Table 5). Figure 15 shows the average ratings of perceived benefit from the technology. Whereas some drivers were unsure or disagreed that the technology was beneficial, most drivers agreed or strongly agreed that the technology was beneficial (61%). There was not a significant difference in reported benefit between the two technologies.

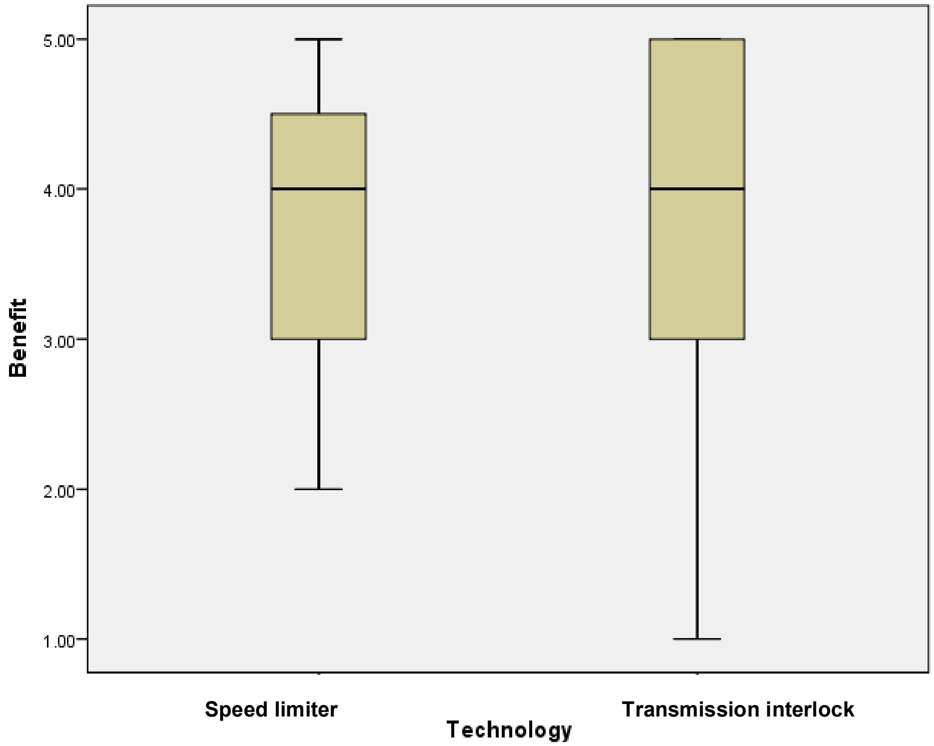

Figure 15. Boxplot of Agreement Ratings That Technology Was Beneficial.

(Note: Ratings are on a 5-point scale with 5 representing highest level of benefit.)

Figure 16 below shows the average ratings of ease of use from the technology. Nearly all drivers agreed or strongly agreed the technology was easy to use (95%). There was not a significant difference in reported ease of use between the two technologies. Individual responses to each question were also shown in Figure 17.

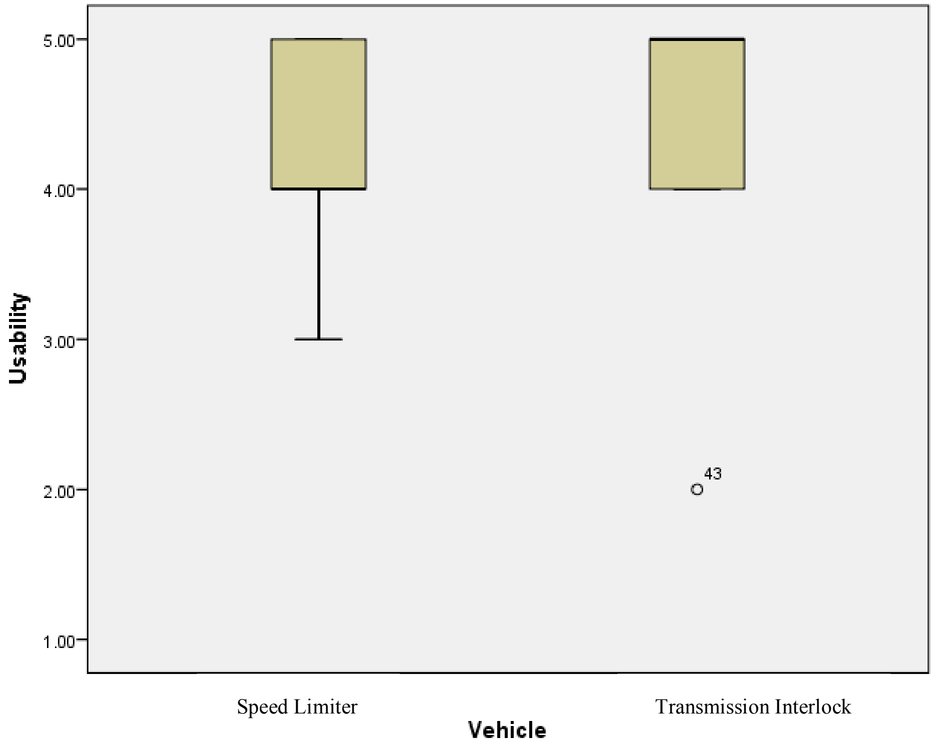

Figure 16. Boxplot of Agreement Ratings That Interaction with Technology Was Easy.

(Note: Ratings are on a 5-point scale with 5 representing highest level of agreement.)

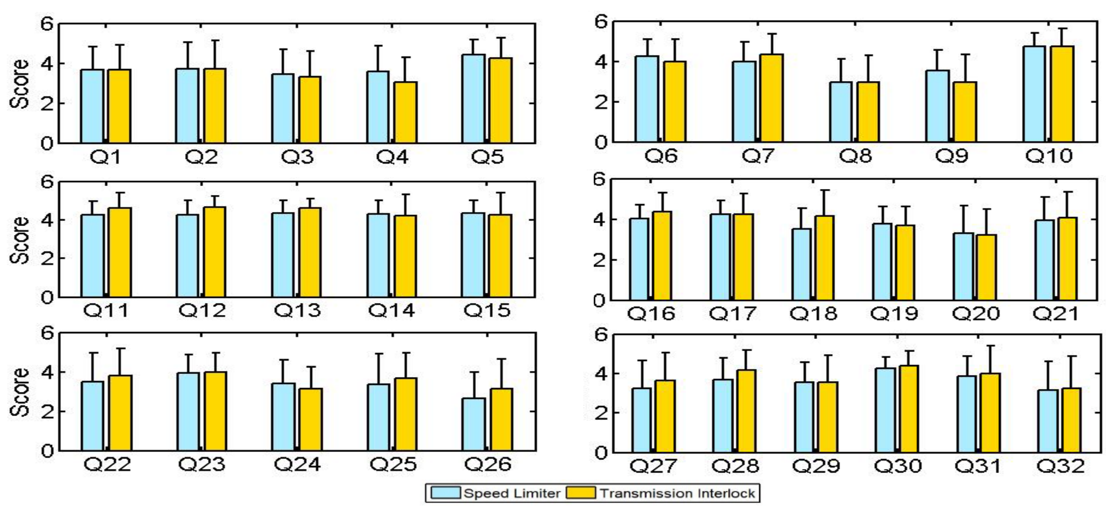

Figure 17. Responses to Individual Questions.

Part A-User rating summary

Drivers perceived their experience with the technology in terms of perceived benefits (including resulting attitudes) and ease of interaction. There was nearly unanimous agreement that the technologies were easy to use. This would be expected because the function of the technology was autonomous and did not required complex interaction by the driver – other than operating the seat belt. However, there was more disagreement about the perceived benefits of the technology even though most drivers agreed that it increased seat belt compliance. Overall, there was not a significant difference in either perceived benefits or ease of operation between the two technologies.

PART A-Individual User Experiences

The complete list of responses to the open-ended questions are listed in Appendix C for the speed limiter and transmission interlock systems, respectively. Here, we discuss the main themes from these responses, and list some specific examples of responses.

Describe what you liked least about the seat belt assurance system.

The common theme for both technologies was that drivers liked that it made them safer by making them wear their seat belt, thereby reducing chances of injury in a crash. In this respect, the technology removed the need for the driver to remember to use the seat belt. Interestingly, they also liked the fact that the technology alleviated them of having to enforce seat belt use by passengers ("I liked not having to remind my daughter to buckle").

The common theme for the speed limiter system was that the audible alarm was annoying ("It will beep even if you're moving a short distance"), and the slowing of the vehicle was perceived to be disturbing ("I constantly forgot about the system and panicked when the car would slow down") and potentially dangerous during hazardous conditions ("That it slowed the vehicle down, that's dangerous being that you never know who could be coming behind the car at a fast pace — or if it's an emergency situation").

The common theme for the transmission interlock system was the frustration from the delay in starting a trip, especially over short distances *where it is perceived that a seat belt is not necessary* ("The fact that I had to put it on before I could shift while I was in a hurry and late for work"). This later point is probably linked to underlying individual beliefs and attitudes about the value and comfort of seat belts.

Describe your most frustrating experience when using the seat belt assurance system.

Common frustrations with the speed limiter system was the audible alarm, slowing down (and needing to apply accelerator to overcome) at unexpected or undesirable times, and the "hassle" of being forced to delay a trip with the time to put on the seat belt when it was not perceived as necessary over a short trip (e.g., drive to postbox near house). It is interesting to note that a speed limiter would not limit very short trips. It would instead keep the vehicle below the threshold speed, but participant perceptions of the system did not recognize this.

Common frustrations with the transmission interlock system were also related to being forced to delay a trip in order to put on the seat belt when it was not perceived as necessary over a short trip (e.g., reverse or move car in the driveway) as well as the hassle of explaining to passengers why the car is stationary while their seat belt is not fastened ("Passenger doesn't know about it so I have to explain why I can't put it into gear").

Describe any changes you would recommend for the seat belt assurance system to make it more acceptable and useful.

The most common recommendations for the speed limiter system was to include a disable option (i.e., not depressing the pedal to override), choose a more pleasant audible sound (i.e., the SBAS also has audio alarms), and provide more time before the vehicle automatically slows down. The most common recommendation for the transmission interlock system technology was to allow gear changing at slow speeds (i.e., a request to change the system from shift interlock to speed limiter), even when the seat belt was not used. It is important to note that these comments come from participant and reflect their perceptions of the system.

Indicate whether you would like to purchase the system and at what price.

Out the 37 participants who responded to this question, 16 drivers responded positively and the average cost they would pay is $625 (ranging from $150 to $ 1,500). Seventeen drivers responded with no willingness to purchase the system while 4 participants were not sure.

Part A-Individual user experiences summary

The safety value of the technology to remind drivers to wear their seat belt was commonly recognized. However, some drivers found the technology unnecessary for short trips and minor maneuvers such as reversing or moving the car on a driveway, etc. An unexpected benefit was the perception that this technology removed the need for drivers to inform and enforce seat belt by passengers. These responses illustrate the variability of individual experiences.

In this study the responses in Part B of the post-study questionnaire (Appendix C) were outside the scope of the study. For this reason, we did not analyzed that portion of the data.

8. Summary and Conclusions

Overall, the Human Factors Study on Seat Belt Assurance System was successful in achieving the study goals: (1) system effectiveness evaluation and (2) unexpected consequences examination. Two prototype SBAS were evaluated, speed limiter and transmission interlock. Based on a power analysis, 48 part-time seat belt users were recruited and their interaction with the SBASs were collected and compared under naturalistic driving settings. A total of 6,254 valid trips were recorded from the 48 participants, equaling 1,785.6 driving hours.

Summary of Key Findings

System effectiveness was measured by two methods, the percent of unbelted driving time and the percent of unbelted trips. The results for both measures showed statistically significant improvements in seat belt use for both the transmission interlock and speed limiter systems in that the percentage of unbelted driving time (or trips) significantly decreased from the baseline period to the treatment period. In general, the percent of unbelted trips resulted in a much higher reduction in value than the percentage of unbelted moving time. This effectiveness was much more apparent for infrequent belt users than for frequent belt users.

Interestingly, the two measures resulted in opposite results regarding the comparisons between the two SBAS systems. The reduction in the percentage of unbelted trips (between treatment and baseline driving) for speed limiter group was much smaller than the reduction in the percentage of unbelted trips for transmission interlock group, (while similar reductions were observed for both SBAS groups by using the percentage of unbelted moving time). One likely explanation is that the transmission interlock system typically stops drivers from moving at the beginning of a trip when unbelted and not cheating, while the speed limiter system still allows unbelted drivers to start a trip unbelted at low speed and then buckle up. It is suggested that the reduction in the percentage of unbelted driving time may be a better indicator for system effectiveness as it takes consideration of the total trip duration as overall exposure.

System defeating strategies were observed through a thorough video review**.** Two main system defeating or cheating strategies were observed, pre-buckling then sitting on the seat belt and waiting out the interlock timer. As the first strategy was observed for both SBAS groups while the second one was only observed in the transmission interlock group, it spears that drivers have adapted cheating strategies based on the limitations in the design of each system.

Eight of 48 drivers were observed cheating the SBAS during some or all of their trips, and the trips with observed cheating comprised 7.6 percent of all trips across the 48 participants. As all 8 drivers who cheated were infrequent belt users, the corresponding likelihood of infrequent belt users defeating the systems is much larger than the for frequent belt users. It was also found that drivers from the transmission interlock group were more likely to cheat the SBAS than drivers from the speed limiter group (odds ratio =2.5), given drivers from transmission system had additional “cheating” method by waiting out interlock timer. Drivers were more likely to cheat during treatment driving when compared to during baseline driving, suggesting the use of the SBAS technology is likely to introduce more cheating behavior (odds ratio =3).

User acceptance was assessed through a post-study questionnaire. Generally, high user acceptance was observed when participants perceived their experience with the technology in terms of perceived benefits (including resulting attitudes) and ease of interaction. Nearly all drivers agreed or strongly agreed the technology was easy to use (95%). There was no significant difference in the reported ease of use between the two technologies.

The safety value of the technology in reminding drivers to wear their seat belt was commonly recognized. However, some drivers found the technology to be unnecessary for short trips and minor maneuvers such as reversing or moving the car on a driveway.

The most common recommendations for the speed limiter system was to include a disable option, choose a more pleasant audible sound, and provide more time before the vehicle automatically slowed down. The most common recommendation for the transmission interlock system technology was to allow gear changing at slow speeds, even when the seat belt was not used.

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Appendix A

OMB Control No. 2127-XXXX
Expiration Date xx/xx/xxxx

Demographic Questionnaire

Subject #______

Supplemental Subject Information

All of this information is kept strictly confidential. We will protect all personally identifying data and information collected in connection with this study to the extent provided by law. Please note that your name is not used in any published reports, or when reporting any results.

Name: ________________________ **Sex:** Male Female (Circle One)

Home Address: ____

____

Work Address: ____

____

Times at work: _________________________

Occupation: _________________________________

(If student, note major; if retired, note former occupation.)

Highest Education Level Completed (Circle One)

High school Some college Bachelor's degree Master's degree MD/JD/Ph.D.

Current Phone Numbers: Home (_____) _____ - _____ **Work** (_____) _____ - _____ **Cell** (_____) _____ - _____

Email address: _______________________

Birth date: _______________ **Current Age**: _____

Driver's License Number: _________________________

Type of car you drive:	Primary:	Year _____	Make _________	Model __________
	Secondary: (if applicable)	Year _____	Make _________	Model __________

What types of safety systems available in your current personal vehicle (circle all applicable):

Forward crash warning; Lane departure warning; Adaptive Cruise Control; Blind spot detection

How many years have you been driving? _____

Approximate total mileage driven over the past year: _______________

On average, how many trips do you drive per week? _____

What is the average duration of each trip?_____

Do you wear glasses? Yes No **Contacts?** Yes No

Appendix B

OMB Control No. 2127-XXXX
Expiration Date xx/xx/xxxx

Eligibility Determination Questionnaire

Hi. Thanks for calling.

Purpose:
We are conducting a study investigating drivers' natural driving behavior on real roads.

Activities:
You will drive one research vehicle equipped with advanced technologies for a total of three weeks. During the three weeks, we would like you to use the research vehicles in place of your personal vehicle. While you drive, a computer located in the trunk will continuously collect data about how and where you drive. Some examples of these types of data collected are your speed and location. Additionally, you will be video and audio recorded while you drive. You can take the vehicle anywhere within the continental US. However, we ask that you don't take the car into Canada or Mexico because we believe that you will have a difficult time getting it back into the country due to the specialized equipment that is on board. If you qualify for the study, you will need to come to Ann Arbor to pick up a car. We will schedule two return visits with you to bring the vehicle back to UMTRI for data downloading and vehicle maintenance. This is an important requirement for participation to make sure the study goes smoothly. The two return visits will be exactly at the end of each week. During your return visits, we will fill up your gas tank for free. You will also be receiving training during your first return visit. This training session lasts about 30 minutes. This training session will help you to get familiar with the vehicle control and advanced in-vehicle technologies.

Compensation:
For your participation in the study, in addition to the use of a car and two free full tanks of gas, you will receive $90.

Overview:
In order to determine your eligibility, I have to ask you some questions regarding your driving experience, age, whether you have a valid driver's license, etc. This should take about ten minutes. Are you interested in proceeding with the questionnaire?

1. What is your age?

2. Gender: male or female?

3. Do you have a valid U.S. driver's license with your photo on it? Are there any restrictions on your driver's license? If you qualify, you will need to bring your driver's license with you to the study session.
   (Exclude if they do not have or cannot produce a valid, unrestricted [typically issued at age 18 — provides unlimited driving privileges to teenagers who have progressed through the graduated system and have an established history of safe driving] driver's license with their photo.)

4. How many years have you been driving?
   (Exclude if less than one year.)

5. How many miles did you drive last year? How many trips did you drive per week on average and how long is each trip on average?
   (Exclude if less than 25% below the mean for their age/gender group or if drive less than 5 trips per week. Source: NPTS.)

6. What type of car do you drive (make, model, model year)? ___________________
   Are there any advanced safety systems in your car? Yes/No

7. How often do you wear your seat belt while driving?

   a) All the time; b) Most of the time; c) Sometimes; d) Only occasionally; e) Never

   7a. Has there been ANY time in the past year that you did not wear your seat belt when you were driving?

   1 Yes
   2 No
   3 don't know
   4 refused

   7b. Of all the trips that you made last month, how often did you wear your seat belt?
   >90% , or <80%?

   7c. Which of the following best describes how often you wear your seat belt when you're a driver? *(Exclude if they answer Always.)*

   1 Always (>90%)
   2 Most of the time (60%~80%)
   3 Some of the time (30%~50%)
   4 Never (<10%)

7d. Which of the following best describes how often you wear your seat belt when you're a front-seat passenger?

1 Always (>90%)
2 Most of the time (60%~80%)
3 Some of the time (30%~50%)
4 Never (<10%)

8. Under the following circumstances, when would you choose *not* to put on your seat belt? (Choose all applicable ones.) *(Exclude if they answer Never.)*

    a) Driving within a few miles of your home;
    b) Only driving on local roads;
    c) Driving out very early in the morning/ very late at night when there is no surrounding traffic;
    d) Driving with your friends;
    e) Traveling alone;
    f) When police are likely to not be present;
    g) Never;
    h) Other___

9. (a) What kind of active safety systems are available in your current vehicle?
    Forward crash warning; Lane departure warning; Adaptive Cruise Control; Blind spot detection; None.

    (b) Which safety system do you like the best?

    (c) Which vehicle feature do you value the most (pick one)?

    Safety; Comfort; Cost(cheap or expensive); Size (compact or big)

10. Do you or any members of your household work in any of the following fields or for these types of companies? (If yes to any, thanks and end.)

    - ❑ Design, engineering, or development of automotive-related technologies
    - ❑ News or media company
    - ❑ An auto manufacturer
    - ❑ A manufacturer, distributor or retailer of automotive parts
    - ❑ An auto mechanic / technician / auto repair shop
    - ❑ A professional driver

11. Have you been convicted of any of moving violations in the past 24 months?

    We would like to review your driving record to determine your eligibility to participate. If you agree to allow UMTRI to review your driving record, the information will be kept strictly confidential to the extent permitted by law and will not be shared with anyone outside of the UMTRI research team. Later, should you choose to participate in our study, we will ask for your driver's license number to be able to review your driving record. Again, your response is voluntary. You may refuse, and UMTRI will not keep any record of your response.

Does the University of Michigan Transportation Research Institute have your permission to request your driving record from the State of Michigan and review it to confirm your eligibility to participate?
(Exclude if permission to access their driving record is denied.)

i) Are you able to drive a car equipped with an automatic transmission without assistive devices or special equipment (for example, pedal extension, hand controls, etc.)?
(Exclude if they answer no.)

j) Do you use any corrective devices to hear or to see? If you qualify, you will need to bring your hearing aid or glasses with you to the study session.
(Exclude if they acknowledge the need for, but fail to use, corrective devices.)

k) Are you currently taking any medicine which may impair your ability to drive? If yes, please explain.
(Exclude if answer is yes.)

Are you interested in participating? Do you have any questions about the study or your participation? I will need your driver license number to review your driving record. If you are qualify for the study, I will send you a packet of materials for you to review prior to coming to pick up a car. The packet will include an informed consent form and several questionnaires that you will need to complete.

Name ____

Address ______________________________________

____

Driver's License # ______________________________________

Home Phone: __________________________ **Work Phone:** __________________________

Cell Phone: __________________________

Appendix C

OMB Control No. 2127-XXXX
Expiration Date xx/xx/xxxx

Vehicle Technology Questionnaire Part A

This questionnaire is designed to measure your opinions about different types of technology that can be installed in vehicles. You have recently had the opportunity to drive a particular vehicle and experience the technology installed in it. From this experience, we would like you to indicate your level of agreement with a series of statements. Your level of agreement with these statements will be used to measure your opinion about the technology.

For this questionnaire, we would like you to focus on your experience with the <**seat belt assurance system**: This system uses sensors to detect when you are not wearing your seat belt and then restricts your vehicle's mobility in order to encourage you to use your seat belt>.[1]

Effectiveness
Please use this rating scale to indicate your level of agreement with these statements about the effectiveness of this vehicle technology.
This technology:

	Disagree Strongly	Disagree	Not Sure	Agree	Agree Strongly
1. Helps me enjoy driving.					
2. Helps me get to my destination.					
3. Helps me avoid traffic hazards.					
4. Prevents crashes.					
5. Reduces the risk of injury if there is a crash.					
6. Benefits my passengers.					
7. Benefits me as a driver.					
8. Makes me drive at safe speeds.					
9. Makes me keep a safe following distance.					
10. Makes me wear my seat belt.					

Efficiency
Please use this rating scale to indicate your level of agreement with these statements about the efficiency of this vehicle technology.

	Disagree Strongly	Disagree	Not Sure	Agree	Agree Strongly
11. It is easy to learn how to use this technology.					
12. This technology is easy to operate.					

[1] Insert the name and description of any technology.

13. I can always remember how to use this technology.					
14. This technology always works reliably.					
15. I understand how this technology works.					
16. This technology does not require lots of my attention.					
17. This technology communicates with me in a way I understand.					
18. This technology does not distract me.					
19. This technology makes it clear when it is not working properly					
20. I can end my interaction with this technology whenever I want.					
21. This technology relieves me from demanding front passengers wear seat belts.					

Satisfaction *Please use this rating scale to indicate your level of agreement with these statements about your level of satisfaction with this vehicle technology.*	Disagree Strongly	Disagree	Not Sure	Agree	Agree Strongly
22. I enjoy this technology.					
23. I trust this technology.					
24. I rely on this technology.					
25. I want this technology in my own car.					
26. I would pay more to have this technology on my next car.					
27. I look forward to using this technology.					
28. I am satisfied with the function design of this technology.					
29. I am never stressed by this technology.					
30. I think the interface of this technology is clear.					
31. I would recommend this technology to my friends.					
32. I would like this technology to work on my rear seat passengers as well.					

Finally, please answer these questions about your experience with this technology:

Describe what you liked most about the <seat belt assurance system>.[2]

____

____

____

____

Describe what you disliked most about the <seat belt assurance system>.

____

____

____

____

Describe your most frustrating experience when using the <seat belt assurance system>.

[2] Insert name of technology.

Describe any changes you would recommend for the <seat belt assurance system> to make it more acceptable and useful.

Do you want to have this system in your vehicle? If yes, how much would you pay to have this technology in your vehicle? $ _____________

Describe what you like/dislike most about the <seat belt assurance system> driver interface features (such as the flashing visual icon or audible chiming) and why?

Describe how you would change the <seat belt assurance system> interface to make it more readable and useful.

What do you like/dislike most about the front passenger feature of the <seat belt assurance system> (i.e., you cannot move the car if your front passenger refuse to buckle up), and why?

How would you recommend changing the <seat belt assurance system>'s front passenger activation feature to make it more acceptable and useful.

Vehicle Technology Questionnaire Part B (Speed Limiter System)

This questionnaire is designed to measure your opinions about different types of technology that can be installed in vehicles. You have recently had the opportunity to drive a particular vehicle and experience the technology installed in it. From this experience, we would like you to indicate your level of agreement with a series of statements. Your level of agreement with these statements will be used to measure your opinion about the technology.

For this questionnaire, we would like you to focus on your experience with the <Navigation System: This system provides active navigation functions to your driving>.[3]

Describe what you liked most about the < **Navigation System** >.

Describe what you disliked most about the < **Navigation System** >.

Describe your most frustrating experience when using the < **Navigation System** >.

Describe any changes you would recommend for the < **Navigation System** > to make it more acceptable and useful.

3

Vehicle Technology Questionnaire Part B (Transmission Interlock System)

This questionnaire is designed to measure your opinions about different types of technology that can be installed in vehicles. You have recently had the opportunity to drive a particular vehicle and experience the technology installed in it. From this experience, we would like you to indicate your level of agreement with a series of statements. Your level of agreement with these statements will be used to measure your opinion about the technology.

For this questionnaire, we would like you to focus on your experience with the <Navigation System: This system provides active navigation functions to your driving>.[4]

Describe what you liked most about the < **On-star System** >.

Describe what you disliked most about the < **On-star System** >.

Describe your most frustrating experience when using the < **On-star System** >.

Describe any changes you would recommend for the < **On-star System** > to make it more acceptable and useful.

[4]

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