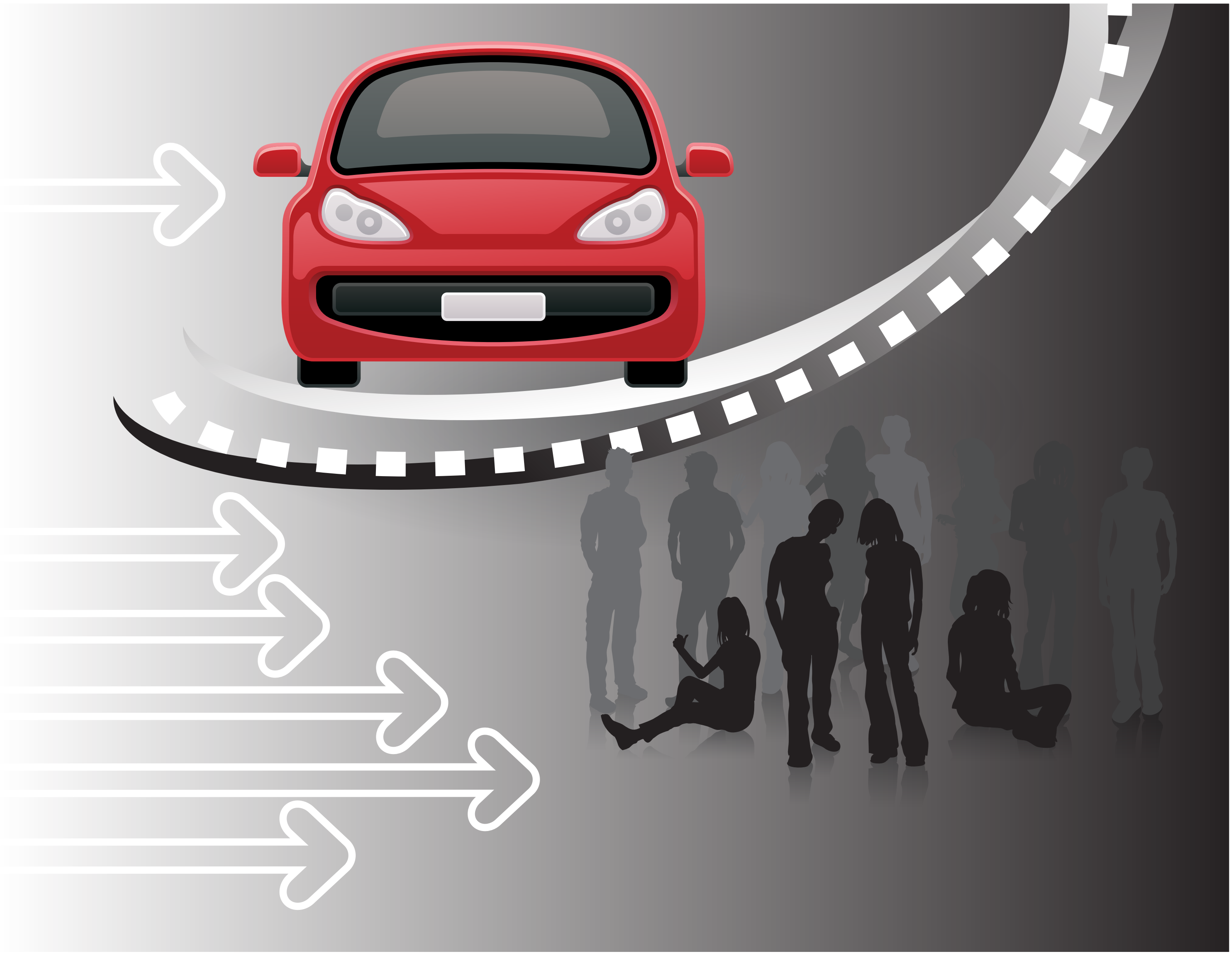
Evaluation of a Prototype Safer Teen Car

Final Report



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16. Abstract
The final report, "Evaluation of a Prototype Safer Teen Car," describes the methods, findings, and recommendations by the University of Minnesota on the practicality and benefits of a system that can provide real-time driver feedback to teen drivers. A prototype Safer Teen Car (STC) system was developed and served as the basis for a field evaluation and as a demonstration unit for stakeholder groups.

The STC designed for this project was comprised of a number of interrelated subsystems, including:

- Teen driver identification subsystem;
- Seat belt detection & enhanced reminder subsystem;
- Passenger presence subsystem;
- Speed monitoring & feedback subsystem;
- Excessive maneuver & feedback subsystem;
- Cell phone use detection & mitigation subsystem; and
- Driving context subsystem.

The findings generally showed improved safety behavior during when the STC system provided feedback. For example, the reduction in the per-mile rate of excessive maneuvers was statistically significant at night, but not during the day. In general, the results indicated reductions in the rates of speeding, excessive maneuvers, and seat belt nonuse.

Overall, the STC was viewed as useful and safety-enhancing, by both teens and parents. Both teens and parents agreed that the STC changed the teens' driving behavior. Parents would generally recommend the STC to other parents.

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A Note on Terminology

In most of its internal and external documents, NHTSA uses the term "Safer," – the comparative form, with the "r" -- in the phrase "Safer Teen Car." The University of Minnesota's Center for Transportation Studies and its ITS (Intelligent Transportation Studies) Institute use the term "Safe," without the "r" comparative ending. In either case, the acronym STC refers to both terms, without regard to the grammar or to which agencies and institutions are using the term. The term "Safer" is used throughout this document except in cases where direct quotation of the "Safe" terminology is quoted.

Executive Summary

This report describes the methods, findings, and recommendations by a research team who conducted research as part of the National Highway Traffic Safety Administration project for "Evaluation of a Prototype Safer Teen Car." The objective of the project was to demonstrate the practicality and benefits of a prototype "Safer Teen Car" (STC), a system that can provide real-time driver feedback to teen drivers. The STC is seen as a parent-controlled, in-vehicle, driver feedback system that may be available as an original equipment feature of future vehicles. This project developed a prototype STC system that served as the basis for a field evaluation and as a demonstration unit for stakeholder groups.

Teenage drivers have much higher rates of crash involvement, injury, and fatality than other driver groups. These rates are exceptionally high for newly licensed drivers and decline rapidly over the first few months of driving experience, but still remain considerably greater than adult driver rates for a period of years. The frequency of risky driving acts and of crash involvement is tempered by the presence of a mature adult passenger in the vehicle with the teen driver. The basis for the beneficial effects of adult presence is not certain. It may be due to some combination of instructive feedback and the potential for some form of negative response or sanction. The adult's influence may thus address teen driver problems caused by limited skill and experience or by intentional risk-related behaviors. The possible benefits appear substantial. After the initial supervised driving phase of a licensure program, it is not required to have an adult present in the vehicle with a teen driver. However, advances in intelligent in-vehicle technology make it possible for the vehicle to monitor various aspects of driver behavior and provide some form of feedback to the driver. Thus, the vehicle itself might serve some of the function of an adult supervisor and help mitigate the teen driver crash problem. NHTSA funded a project titled "An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers" to examine potential approaches for mitigating teen crash risk using in-vehicle technology. The results indicated that a variety of feedback strategies were feasible and promising and that current technologies could address the key behavioral factors in teen crashes (Lerner et al., 2010).

This project employed vehicle-based sensing to provide real-time feedback to teen drivers. It specifically did not include "reporting" programs, in which driver performance data are summarized and transmitted to parents or others for review and use in coaching the teen. Rather, the focus was on direct, immediate feedback to the driver and/or some adaptation of vehicle response (e.g., cut-off of the infotainment system or speed limitation).

To accomplish the project objectives, the project was comprised of a series of tasks:

1. Specify subsystem functions and their performance requirements: This task determined what functions the STC should encompass and the functional requirements and interface features needed to achieve that functionality.
2. Determine enabling technologies that meet the functional and interface specifications: This task explored the hardware and software technologies that could be used to meet the STC performance requirements.
3. Develop and review data collection plan: This task developed a detailed data collection and analysis plan for subsequent project activities.

4. Conduct evaluation of subsystems: In this task, the planned field evaluation method was pilot tested through experimental evaluations of individual subsystems of the STC; this was based on adapting the conceptual original equipment manufacturer (OEM) STC system to a temporary, non-destructive platform that could be installed in participants' own vehicles for several weeks.
5. Build and demonstrate to NHTSA the prototype car: STC functionality was built into a dedicated prototype vehicle; the car was demonstrated to NHTSA and agency feedback was incorporated into refinements of the system.
6. Conduct stakeholder outreach and evaluations of prototype vehicles, develop parent/teen information program: The prototype STC car was demonstrated to the expert community through demonstration drives and feedback was provided. Feedback from automotive OEMs was also solicited through phone and e-mail discussions. Subsequently, the full integrated STC concept was field-tested with a group of teen drivers, again adapting the conceptual OEM STC system to a temporary, non-destructive platform that could be installed in participants' own vehicles.
7. Document final specifications: Formal performance specifications for the STC were developed and documented.
8. Generate final report and briefing: The final report was developed and a briefing was provided to NHTSA.

The STC designed for this project was comprised of a number of interrelated subsystems. These included:

- Teen driver identification subsystem;
- Seat belt detection and enhanced reminder subsystem;
- Passenger presence subsystem;
- Speed monitoring and feedback subsystem;
- Excessive maneuver and feedback subsystem;
- Cell phone use detection and mitigation subsystem; and
- Driving context subsystem.

The STC system was adaptive; the criteria for operation of some of the subsystems depended in part on the status of other subsystems. For example, the threshold for triggering a speeding warning was influenced by the use of seat belts, the number of vehicle occupants, and time of day.

A description of the planned STC was circulated to nine automotive OEMs for comment. The overall response was generally positive, with a number of suggestions for refinement or expansion. The approach was also viewed as practical, although there were some concerns with the reliability or practicality of certain components.

The STC design was implemented in a dedicated demonstration vehicle. Demonstration drives were provided to experts and stakeholders at two venues: the annual meeting of the Human Factors and Ergonomics Society and a briefing at NHTSA headquarters in Washington, DC. Again the feedback was quite positive, with a few recommendations for improvement.

A subsystem pilot study was conducted to obtain preliminary information on system performance, driver response, study procedures, and teen and parent consumer acceptance. STC systems were installed in 28 teens' vehicles (14 in rural/suburban Minnesota and 14 in urban/suburban Maryland).

For this subsystem pilot test, each vehicle had the seat belt subsystem activated, but used only one other system among speed monitoring, excessive maneuvers, or cell phone use. Based on the findings of this pilot, hardware, software, and procedures were refined for the full system evaluation. The cell phone use system was found to be highly unreliable under field conditions, and a renewed search found no practical alternative approaches, therefore, the cell phone use subsystem was omitted from the full system evaluation.

The field evaluation of the STC included 30 participants, half at each site (Minnesota or Maryland) and spanned a 10-week data collection period for each participant. The procedure included a 2-week initial baseline period, a 6-week treatment period, and a 2-week transfer period. During the baseline and transfer stages, the system collected data but no feedback was provided to the driver. During the treatment stage, all of the subsystems were active. For descriptive purposes, the treatment stage had three sub-phases: immediate (first 2 weeks of treatment), short term (3rd and 4th week of treatment) and long term (final 2 weeks of treatment).

The findings generally showed improved safety behavior during the treatment period, although only a limited number of comparisons achieved statistical significance. For example, the reduction in the per-mile rate of excessive maneuvers was statistically significant at night, but not during the day. The specific statistically significant comparisons indicated reductions in the rates of speeding, excessive maneuvers, and seat belt nonuse in certain occupant locations. Non-significant differences were usually in the same direction.

In addition to the driving behavior measures, the field evaluation also collected subjective opinions of teens and parents upon completion of the experiment. Overall, the STC was viewed as useful and safety-enhancing, by both teens and parents. Both teens and parents agreed that the STC changed the teens' driving behavior. Parents would generally recommend (sometimes with reservations) the STC to other parents and did not view the system as an invasion of privacy.

The evaluation of the specific implementation of a STC system was limited in a number of ways in this study. The number of participants was relatively small (n =30) and the performance of the system was less than optimal due to the need to implement a low-cost portable version of the STC that could be installed in teens' personal vehicles without damage or marring. Nonetheless, the overall effects of driving performance were positive in terms of parent and teen consumer attitudes, and expert stakeholder perceptions of the concept. The project provided a number of recommendations for the design of STC systems and refinements that might be made.

1 Background and Objectives

This document is the project final report for "Evaluation of a Prototype Safer Teen Car," conducted by Westat, Inc., and the University of Minnesota Intelligent Transportation Systems Institute for the National Highway Traffic Safety Administration.

The Safer Teen Car was conceived as a prototype for a manufacturer-provided in-vehicle system that will present teen drivers with real-time feedback and/or adaptation of some vehicle response aspect based on driver performance and situational factors. The system is designed to recognize when the driver is the teen, so that the STC functions are only activated for appropriate drivers.

This document describes the activities and findings of the project and the authors' recommendations and specifications for STC systems that automobile OEMs might incorporate into future vehicles.

1.1 Teen crash characteristics and vehicle-based feedback and adaptation

Teenage drivers have much higher rates of crash involvement, injury, and fatality than other driver groups. These rates are exceptionally high for newly licensed drivers and decline rapidly over the first few months of driving experience, but still remain considerably greater than mature driver rates for a period of years. However, the frequency of risky driving acts and of crash involvement is tempered by the presence of a mature adult passenger in the vehicle with the teen driver. Ouimet et al. (2010) estimated that for 15- to 20-year-old male drivers, the fatal crash rate per mile driven with a mature (35 or older) male passenger was only 31 percent of the rate when a young driver was driving alone. With a mature female passenger, the young male driver fatal crash rate had a greater reduction (11% of the rate when driving alone). There was a similar reduction in crash rates for young female drivers, although the influence of passenger gender was different, with an 18-percent reduction in crash rate when accompanied with a mature (35 and older) male driver and a 37-percent reduction when accompanied with a mature female driver (35 and older) compared to when driving alone. Mayhew, Simpson, and Pak (2003) found a large difference in novice driver crash rates between driving alone and supervised driving in the first couple of months of licensure; driver-alone fatality rates dropped sharply when teens had accrued driving experience within the first few months but remained several times the supervised driving rate for well beyond a year. Simons-Morton et al. (2011) report naturalistic driving data from 42 newly licensed drivers whose vehicles were equipped with recording systems. Combined crash and near-crash rates (primarily near-crash events) were 75 percent lower in the presence of adult passengers, relative to driving alone. Risky driving (as measured by a composite index that included a variety of behaviors) was 67 percent lower with adult passengers. Thus teen driver risky driving, crashes, and fatalities all are moderated by the presence of an adult.

The precise beneficial effect of adult presence is not clear. It may be due to some combination of instructive feedback or the potential for some form of negative response or sanction. Thus, the adult's influence may address teen driver problems caused by limited skill and experience or by intentional risk-related behaviors. In any case, the possible benefits appear substantial. After the initial supervised driving phase of a licensure program, it is generally unlikely that a persistent adult presence is maintained in the vehicle with a teen driver. However, advances in intelligent in-vehicle technology now make it possible for the vehicle itself to monitor various aspects of driver behavior and provide some form of driver feedback. Thus the vehicle itself might serve some of the function of an adult supervisor and help mitigate the teen driver crash problem. NHTSA funded a project titled "An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers" to examine potential approaches using in-vehicle technology. The project found that a variety of feedback strategies were feasible and promising and that current technologies could address the key behavioral factors that appear to be most significant in teen crashes (Lerner et al., 2010).

The Lerner report identified three broad categories of feedback based on teen driver monitoring. One possibility is for the collected data to be summarized in some report form and transmitted to parents or others for review and use in coaching the teen. There have been a number of evaluation studies of such reporting systems and they have been found to be effective to varying degrees in reducing risky teen driver behavior (e.g., Farmer, Kirley, & McCartt, 2010; McGehee, Raby, Carney, Lee, & Reyes, 2007). However, this reporting strategy relies on a program of data collection, transmission, processing, communication, and supervisory action. Two other strategies (in-vehicle feedback and vehicle adaptation) do not require this, but rather respond to driving situations in real time. An in-vehicle feedback system provides the teen driver with real-time information on unsafe behaviors (e.g., speeding). This real-time feedback may be seen as informational (informing about a driving error) or as motivational (e.g., annoying to the driver). The "vehicle adaptation" strategy is when there is some change to the vehicle's response based on the driver's behavior. For example, speed may be restricted or the audio of the infotainment system may be turned off. In-vehicle feedback strategies and vehicle adaptation strategies have the virtue of not requiring any associated cooperative "program." If these feedback or vehicle adaptation functions are available in the vehicle as an owner's selectable feature, an adult may implement this feature at will, without any need to participate with an outside entity. In-vehicle feedback strategies and vehicle adaptation strategies are the focus of the present project.

There has only been limited implementation of these strategies in current vehicles. The Ford MyKey system is the best example at the time of this report. It demonstrates both the feasibility and automotive industry interest in vehicle-based feedback and adaptation systems for teens. This industry interest was confirmed in a stakeholder workshop (reported in Lerner et al., 2010). Based on this, NHTSA recognized that industry implementation of such systems might be encouraged by a demonstration of an effective prototype "teen vehicle."

1.2 Project objectives

The purpose of this project was to develop and demonstrate a prototype system to evaluate the potential of vehicle-based feedback and adaptation for improving teen driver safety. The focus was on real-time feedback and response to the teen driver, rather than any program based on recording and reporting on unsafe behaviors for review by parents or others. The intent was to demonstrate the type of system that realistically might be provided by automotive industry OEMs as original equipment systems or options.

To accomplish this, the project included the following objectives:

- Determine the potential effectiveness and acceptability of vehicle technologies that provide in-vehicle feedback to the driver and/or adapt some aspect of vehicle response.
- Specify requirements for vehicle integration, system operation, and interface design
- Determine what information parents and teens need about the STC concept to motivate them to purchase vehicles incorporating these technologies.

1.3 Project overview

To accomplish these objectives, the project was comprised of a series of tasks:

1. Specify subsystem functions and their performance requirements: This task was used to determine what functions the STC should encompass and the functional requirements and interface features needed to achieve that functionality. Decisions were based on the research literature on teen drivers and particularly upon the findings and recommendations of a NHTSA project (Lerner et al., 2010) that specifically investigated the emerging technological opportunities for monitoring teen drivers.
2. Determine enabling technologies that meet the functional and interface specifications: This task was used to explore the hardware and software technologies that could be used to meet the STC performance requirements.
3. Develop and review data collection plan: This task was used to develop a detailed data collection and analysis plan for subsequent project activities.
4. Conduct evaluation of subsystems: In this task, the planned field evaluation method was pilot-tested through experimental evaluations of individual subsystems of the STC; this was based on adapting the conceptual OEM STC system to a temporary, non-destructive platform that could be installed in participants' own vehicles for several weeks.
5. Build and demonstrate to NHTSA the prototype car: STC functionality was built into a dedicated prototype vehicle; the car was demonstrated to NHTSA and agency feedback was incorporated into refinements of the system.
6. Conduct stakeholder outreach and evaluation of prototype vehicles, develop parent/teen information program: The prototype STC car was demonstrated to the expert community (automotive OEMs) through demonstration drives. Feedback was provided through phone and e-mail discussions. Subsequently, the full integrated STC concept was field-tested with a group of teen drivers, adapting the conceptual OEM STC system to a temporary, non-destructive platform that could be installed in participants' own vehicles. Based on the results, a parent/teen driving program was outlined.
7. Document final specifications: Formal performance specifications for the STC were developed and documented.
8. Generate final report and briefing: The final report was developed and a briefing was provided to NHTSA.

In summary, the STC design was conceptualized as a set of integrated subsystems that provide continual and immediate feedback directly to the young driver about his/her driving performance. Requirements were developed for those subsystems and their corresponding driver interfaces. These requirements guided a search for corresponding equipment. The design was further guided by OEM feedback on the basic STC concept, the development and presentation of a demonstration vehicle, and a pilot field test of selected STC subsystems. The pilot results were then applied to a full test of STC Systems in which all successful subsystems were integrated into one system. The STC system, which included adaptive interactions among the subsystems, was tested in a second FOT. The research results from this project led to a final specification for an STC comprised of multiple, adaptive subsystems. The remainder of this report describes the methods, findings, and authors' recommendations of the project, as derived from this set of activities.

2 Prototype System Design

The first task of the project was to identify and document a prototype system design that included a number of performance requirements based on three levels of vehicle implementation: an "ideal" (i.e., OEM) implementation, a demonstration vehicle, and field operational test (FOT). These levels provided a distinct conceptual framework to plan and implement STC subsystems based on access or restrictions to vehicular data and functionality (e.g., vehicle internal computer data). This section of the document provides a brief overview of the system functionalities and outlines the proposed prototype STC based on the conceptual levels of implementation.

2.1 Performance requirements

The prototype STC system three categories of integrated subsystems:

- Driver recognition: identifies driver type (teen, adult) and engages STC functions as a result.
- Driver behaviors: monitors teen driver behaviors and provides feedback or adapts the vehicle features.
- Driving context: indicates the conditions under which the driver behaviors are occurring and thus the system can adapt feedback based on the context.

Multiple subsystems were created to provide a range of adaptive features and feedback based on real-time information. A requirement was that subsystems must integrate and influence other subsystems based on a set of predefined and preprogrammed thresholds. For example, the context subsystem, which monitors time of day, influenced the speed subsystem such that feedback to teens occurred at lower thresholds for nighttime speeds compared to daytime speeds.

Based on the three general driver categories above, the Safer Teen Car system concept was explored using three levels of implementation. These implementation efforts allowed the research team to identify an ideal implementation of an STC system and conversely what was achievable at different implementation levels. These levels are:

- Ideal implementation (Ideal) - A conceptual system was developed that used the resources and scope that an OEM has with access to all types of vehicle hardware features and software information.
- Prototype demonstration vehicle (Demo) - A system developed by the project team with the intention to demonstrate STC on a research vehicle.
- Field operational test (FOT) - A system developed by the project team intended for widespread deployment of safer teen subsystems in participant vehicles during a research effort.

The ultimate objective of this project was to recommend a prototype STC that represents a realistic and practical implementation for OEMs. However, for purposes of developing a demonstration vehicle and for FOT evaluation, there are important constraints on implementing certain functions. Subsystems that may be practical for an OEM to adopt in a new vehicle may not be practical for a research project such as this. This is due to a variety of factors such as access to data already present in the vehicle, difficulties of installation in a current vehicle, the variety of differences among participant-owned vehicles for the FOT, and the need not to mar or damage a research participant's vehicle. For such reasons, it is necessary to distinguish the requirements for each of the three implementations: Ideal (OEM), demo vehicle, and FOT. These three contexts have inherent and obvious differences and the proposed system functions are described based on these differences in the next section.

2.2 Proposed system

The proposed system needed to address the most common risk factors for teens, such as seat belt nonuse, speeding, and distraction due to secondary tasks. Based on previous teen driver research the following subsystems were proposed for the ideal implementation and employed for the demonstration vehicle and FOT testing. These were:

- Teen driver identification subsystem (TDIS);
- Seat belt detection and enhanced reminder subsystem (SBDRS);
- Passenger presence subsystem (PPS);
- Speed monitoring and feedback subsystem (SMFS);
- Excessive maneuver and feedback subsystem (EMFS);
- Cell phone use detection and mitigation subsystem (CDMS); and
- Driving context subsystem (DCS).

One significant feature of the STC system is that it is adaptive, in the sense that the criteria for operation of some of the subsystems depended in part on the status of other subsystems. For example, the threshold for triggering a stronger speeding warning was influenced by the use of seat belts, the number of vehicle occupants and whether there were nighttime driving conditions. In this sense, the system became less tolerant of a given degree of deviation from ideal behavior when it sensed other improper behaviors or risk factors.

2.2.1 Teen driver identification subsystem overview

The goal of the TDIS was to identify when a teen driver was operating the vehicle. When a teen driver was identified, this subsystem allowed the activation of other subsystems in the vehicle that were part of the STC. An STC "smart key" gave the best solution to identify a teen driver. A smart key required minimal interaction from a teen, had a high accuracy rate, and had minimal circumvention to its operation.

An ideal OEM-installed implementation of the TDIS would be based on detection and recognition of a smart key. Dependent on key type (e.g., teen or adult) the subsystems would activate or remain off. When two keys are detected the system should provide a choice between adult or teen mode with a default selection that activates the STC subsystems.

For the demonstration and FOT implementation an analogous system that mimicked the behavior of the electronic key, a radio frequency identification (RFID) system was used. Upon recognition of a specific signal from an RFID card carried by the adult the STC allowed a choice between teen and adult driving modes. The teen mode could either be selected or was the default mode if no choice was made after 10 seconds. If the adult mode was selected then all the STC functions and adaptation behavior were turned off.

The TDIS was the first system that activated whenever a vehicle was started and as such was not dependent on the operation of other subsystems.

2.2.2 Seat belt detection and enhanced reminder subsystem overview

The goal of the SBDRS was to remind and motivate vehicle occupants to use their seat belts. When in "teen" mode, the seat belt reminder system was more aggressive than in "adult" mode. The design of seat belt reminder systems represents some trade-off between features that are highly motivating of seat belt use versus problems of driver annoyance and consumer acceptance. The details of an optimal trade-off may be different for teens, as compared to adults, since teens are at greater crash risk, have overall lower seat belt use rates than adults, may not show as good judgment in risky decision-making, and of course, are minors under parental guidance. Various studies (e.g., Eby et al., 2004; Lerner et al., 2009) have specifically researched this issue and developed recommendations for an effective teen seat belt reminder system. The SBDRS was based on these recommendations.

When activated by a teen driver, an ideal OEM-installed implementation should detect occupants in multiple seating positions depending on vehicle type and size. Information about the passenger seat belt status should be provided to the driver. A verbal reminder to fasten one's seat belt should be provided in addition to a visual icon for both driver and passengers after the ignition is engaged. If the vehicle begins to move the seat belt warnings transitions into a motivator phase that should continue to cycle while any belt remains unbuckled. Additional restrictions during the motivator phase could include infotainment lockouts: no belts, no music.

For the demonstration vehicle and FOT implementation, the basic concepts of the ideal implementation were followed. The demonstration vehicle used an infotainment lockout similar to the ideal OEM-installed implementation. Furthermore, both the demonstration and FOT set-ups provided visual and auditory alerts. The FOT presented the visual alerts on a temporarily installed display located on top of the participants' dashboard whereas the demonstration vehicle's display was mounted in the center stack. Both vehicle set-ups had verbal and visual alerts that included a verbal reminder after ignition if the driver was unbuckled and a motivational reminder that cycled when the vehicle was in drive or reverse.

The demonstration and FOT implementation had a subsystem that monitored passenger seat belt status. This subsystem detected occupant presence and seat belt status at each seating position in the vehicle, displayed seat-specific belt status to the driver, and issued periodic voice messages if any passenger remained unbelted.

2.2.3 Passenger presence subsystem overview

The PPS is a support function for the seat belt and driving behavior feedback. The detection of passengers complements the seat belt detection system to recognize passenger seating positions and factor in non-compliance.

OEMs already use passenger detection technology (pressure sensors integrated into vehicle seats) to determine passenger presence for air bag deployment functions. This type of detection and information may be available for use with seat belt compliance, speed monitoring, and excessive maneuver algorithms. For example, the number of passengers and their seat belt use can be integrated into checking teen GDL requirements and compliance. For the OEM systems, the interface for this subsystem should be "invisible" to the driver and passengers except at vehicle start-up as a status check.

For the demonstration vehicle and initial FOT testing, a passive infrared (PIR) system was mounted beneath each passenger seat to detect heat signatures from occupants' legs. This implementation was a compromise from the OEM version. Other compromises included displaying passenger presence as an indication of subsystem status.

For the FOT implementation, an additional challenge was that the system had to be incorporated into a variety of different vehicles. General requirements for the FOT tests included low power consumption, not marring the participant's vehicle, and keeping the system inconspicuous. The subsystem evaluation provided valuable input for the FOT about reliability and passenger detection and changes were instituted based on this information.

Finally, the PPS is necessary for input into the SBDRS and allows increased functionality for the speed monitoring and feedback subsystem and excessive maneuver and feedback subsystem by providing a valuable contextual factor (e.g., passenger presence).

2.2.4 Speed monitoring and feedback subsystem overview

The SMFS identified the location of the vehicle (via global positioning system information) and corresponding posted speed limit of the road segment on which the vehicle was traveling. The SMFS provided information to the driver about the current posted speed limit, when available, via a display. When the SMFS determined the vehicle exceeded the speed limit (by a predefined threshold) there was visual and auditory feedback. A mild auditory warning (a single beep) was given when the posted speed limit was exceeded by 2 mph and a stronger auditory warnings (a verbal message and 1-second buzzer) were given at a higher speed threshold (e.g., 10 mph over the posted speed limit). A third, even stronger warning was issued at speeds over 80 mph (a verbal message and a longer buzzer). For the mild speed warning the single beep only occurred one time when the vehicle remained within the speed tolerance zone and the speed limit did not change. The mild speed warning gave participants speed awareness information within a speed tolerance zone. There were occasions when participants' speed often varied above and below the mild speed tolerance zone. In these situations where speed may have wavered above and below the 2 mph threshold, the warning would not occur more than once every 5 minutes. For the stronger speed warning the frequency of the auditory feedback was given 10 seconds after the initial warning and again 20 seconds after that if the speed had not been reduced below the warning threshold. If teens continued to speed, the warning threshold would reset after 5 minutes. The strongest warning issued at speeds over 80 mph included a speech warning and a long buzz sound. These levels were also affected by the other subsystems such that if thresholds were exceeded in allied subsystems (e.g., SBDRS or PPS) the warning thresholds used as the basis to provide SMFS-related feedback decreased and therefore feedback and vehicle adaptations occurred sooner.

An ideal implementation could visually display advisory limits (e.g., curve warnings) in addition to regulatory speed limits. Updated travel information based on GPS coordinates could display real-time information for drivers such as active work zones and school zone warnings. An ideal implementation would also incorporate inputs from the context subsystem and could provide warnings to the driver based on environmental conditions and recommended speeds.

The demonstration and FOT vehicle implementation displayed speed information, when available, through visual icons presented on their respective displays. The mild and strong auditory warnings were also implemented and provided drivers with feedback when they had exceeded the predetermined speed limit threshold. The SMFS also fed into the adaptive nature of the STC and the other subsystems. For example, if teens violated the speed thresholds this in turn would reduce the warnings thresholds for the Excessive Maneuver subsystem, resulting in increased sensitivity for excessive maneuvers. The impact of other subsystems on the feedback provided by the SMFS and the adaptive attributes of the system are shown in Table 2-1. As the number of cautionary inputs increased the point at which the teen would receive feedback was sooner. The feedback from the SMFS follows closely with prior work from intelligent speed adaptation systems (ISA), where speed reduction was identified based on a number of levels presented to a driver (Brookhuis & de Waard, 1999).

Table 2-1 Strong speed warning thresholds with cautionary inputs from other subsystems.

Posted Speed Limit	Auditory Speed Warning Threshold				
	No Cautionary Inputs	Seat Belt Violation	One Cautionary Input	Two Cautionary Inputs	Three or More Cautionary Inputs
Less than 25 mph	posted speed limit +2 mph	posted speed limit +2 mph	posted speed limit +2 mph	posted speed limit +2 mph	posted speed limit +2 mph
25 mph	+5 mph	posted speed limit +2 mph	+ 3 mph	posted speed limit +2 mph	posted speed limit +2 mph
30 to 45 mph	+10 mph	posted speed limit +2 mph	+6 mph	+3 mph	posted speed limit +2 mph
50 to 65 mph	+15 mph	posted speed limit +2 mph	+10 mph	+5 mph	posted speed limit +2 mph
70 mph	+10 mph	posted speed limit +2 mph	+6 mph	+3 mph	posted speed limit +2 mph
75 mph	+5 mph	posted speed limit +2 mph	+ 3 mph	posted speed limit +2 mph	posted speed limit +2 mph
80 mph	posted speed limit	posted speed limit	posted speed limit	posted speed limit	posted speed limit

Overall, the speed warning subsystem and corresponding visual and auditory warnings took precedence over the other subsystems and received information from these subsystems based on passenger presence, seat belt use, excessive maneuvers, and context (time of day) subsystems.

2.2.5 Excessive maneuver and feedback subsystem overview

The EMFS monitors lateral and longitudinal forces in the vehicle using accelerometers and alerts the driver if those forces exceed predetermined thresholds. The system consists of two components. The first monitored acceleration (gravitational) force of a vehicle in both lateral and longitudinal directions. The second provided feedback of the excessive maneuver by displaying an icon and sounding an alert indicating a control threshold had been exceeded. Other subsystems also interfaced with the EMFS such that EMFS thresholds were modified based on seat belt use, passenger presence, cell phone use, or contextual factors.

An ideal implementation should include immediate feedback displayed either as auditory, visual, or both. The feedback should be presented within the driver's line of sight with an adequate duration (e.g., 5 seconds) to provide relevant and deterrent feedback. The visual feedback should include a dangerous maneuver icon and specific text stating "Dangerous Maneuver." Finally, as additional motivation, an infotainment lockout should occur when the EMFS is activated.

The demonstration vehicle and FOT implementations had similar operational characteristics as an ideal implementation. However, the demonstration vehicle had a display mounted in the center stack and the FOT vehicles had small displays located on the top of the dashboard. Furthermore, the demonstration vehicle incorporated an additional motivation strategy by locking out the infotainment system. The infotainment system lock out was not possible on the FOT vehicles.

The excessive maneuver feedback or other transient warnings such as speed take precedence over static warnings such as seat belts. The excessive maneuver subsystem received input from the passenger presence, seat belt detection, distraction (e.g., cell phone use), and driving context subsystems. The adaptive component of the EMFS is seen in Table 2-2 where the impact of speeding and other cautionary inputs is shown in the reduction of the EMFS thresholds.

Table 2-2 Excessive maneuver warning thresholds with cautionary inputs from other subsystems.

Posted Speed Limit	Auditory Excessive Maneuver Warning Threshold				
	No Cautionary Inputs	Seat Belt Violation	One Cautionary Input	Two Cautionary Inputs	Three or More Cautionary Inputs
Less than 25 mph	.50 g	.45 g	.45	.40 g	.35 g
25 mph	.50 g	.45 g	.45	.40 g	.35 g
30 to 45 mph	.50 g	.40 g	.40 g	.35 g	.30 g
50 to 65 mph	.50 g	.35 g	.35 g	.30 g	.30 g
70 mph	.50 g	.30 g	.30 g	.30 g	.30 g
75 mph	.50 g	.30 g	.30 g	.30 g	.30 g
80 mph	.50 g	.30 g	.30 g	.30 g	.30 g

Note, red, yellow, brown, blue, and white cells indicate stringent, moderate, mild, minimal, and standard criterion thresholds, respectively.

2.2.6 Cell phone use detection and mitigation subsystem overview

The goals of the CDMS were to reduce the probability that drivers will use their cell phones and to mitigate the effects of driver cell phone use on crash risk and severity. The CDMS needs to detect cell phone use while the vehicle is in motion and manage those incoming and outgoing calls based on critical needs (e.g., allowing 911 calls). An ideal implementation would be able to distinguish driver cell phone use from passenger cell phone use. Although some technological approaches appear promising, at this time none of the technologies that were explored were able to reliably distinguish between cell phone users within the vehicle. Therefore, the subsystem focus was on detection of any cell phone use while the teen was driving.

The ideal implementation would consist of both visual and auditory components. For example, when a cell phone is detected, a visual warning should be presented that depicts cell phone use (a cell phone image with a line through it). Text below the icon should indicate “Don’t use cell phone while driving.” In addition, an auditory message such as “Cell phone use detected, please hang up” may be used to reinforce the feedback. The initial detection message should act as a mild reminder. If continued use is detected, a stronger motivator phase should be implemented and should lock out the infotainment center and present louder tones/messages. The lockout should continue for at least

30 seconds after cell phone use is no longer detected to encourage drivers to focus on driving. The visual display and the auditory interface functions should continue for 5 seconds after the conclusion of cell phone call.

The information above describes an ideal implementation and the demonstration had these changes: the CDMS volume was not dependent on ambient vehicle noise and did not increase in volume with continued cell phone use. The infotainment system was not locked out, the cell phone call management subsystem was also not included. It should be noted that only phones without "smart phone" capabilities could be detected by the CDMS for the demonstration vehicle.

The FOT implementation for the CDMS did not occur due to significant limitations in accurately detecting cell phone use during the subsystem evaluation (e.g., see Section 3).

If the CDMS can be implemented it should interact directly with the SMFS such that cell phone use should reduce the thresholds for SMFS and EMFS.

2.2.7 Driving context subsystem overview

The DCS was intended to recognize the presence of external risk factors that may be incorporated into the algorithms for driver feedback or vehicle adaptation. The focus was on environmental factors related to visibility limitations or vehicle control, some of which can be monitored through vehicle dynamics (e.g., traction control).

The ideal implementation should take advantage of information that can be inferred from the several vehicle sensing systems. For example, time of day can be obtained from GPS and vehicle clock time, precipitation may be inferred from windshield wiper use and roadway icing can be inferred from temperature, humidity, and traction control features.

For the demonstration and FOT implementation efforts only the time of day was used. The time of day was collected from the GPS signal obtained as part of the speed management subsystem and then compared to sunset and sunrise times to identify day or night driving.

No other subsystems were needed for this subsystem to operate. However, the DCS was necessary for input into the SMFS and EMFS by providing important driving context factors (e.g., day or night). The DCS combined with data from inside the vehicle (passengers, distraction, seat belt use) served to refine the response of other subsystems.

2.2.8 Enabling technologies that meet STC functional and interface specifications

This task examined the functional and interface specifications for each of the proposed subsystems to identify technologies and equipment that would implement those subsystems with regard to cost, performance and simplicity. Five FOT vehicle packs were built and installed to further test the reliability in different vehicle types. Details of this task are presented in Appendix H.

3 Preliminary Assessment

Prior to a full assessment of the prototype system described in Section 2, several project activities provided preliminary information that was useful for confirming or refining aspects of the full system and its planned empirical evaluation. First, automotive industry feedback was sought on the planned system. Second, a prototype vehicle was developed and demonstrations were provided to stakeholders and experts in driver behavior. Finally, individual subsystems were installed in teen participants' vehicles in a pilot test of the full system evaluation procedure. This pilot provided insight on experimental procedures as well as providing initial parent and teen feedback about the system itself. The findings of each of these preliminary assessment activities are described in the sections that follow.

3.1 Automotive industry feedback

Nine major automobile manufacturers were contacted in April 2010 with a request to provide their "informed opinion regarding the feasibility and usefulness of the planned system as an example of what production vehicles might provide in the future." The request document described the project background, project objectives, and the planned system. The document listed the four questions:

1. Do you consider the general concept of a vehicle-based system that recognizes a teen driver and provides driver feedback/vehicle performance adaptation to be a valuable idea? If no, why not?
2. Are there aspects of the system we have described that you see as impractical? We would like your thoughts on the practicality of each subsystem, as well as the overall integrated system. Please respond for each item below, and if you feel something is impractical, indicate why.
    - Teen driver identification subsystem
    - Seat belt detection and enhanced reminder subsystem
    - Passenger presence subsystem
    - Speed monitoring and feedback subsystem
    - Excessive maneuver subsystem
    - Cell phone use detection and mitigation subsystem
    - Driving context subsystem
    - Total (integrated) system
3. Are there additional functions that you would like to see included in a prototype safer teen car?
4. Do you feel there would be good consumer interest and acceptance in this sort of vehicle feature? Can you suggest anything to improve consumer acceptance?

The request acknowledged that there may be proprietary concerns or other considerations that limit responses to some items and that the researchers appreciate whatever opinion and insight the respondent was able to provide. It was also indicated that there would be no attribution of individual comments. Reviewer opinions were to be integrated and synthesized for reporting.

Responses were received from seven of the nine companies contacted. One company replied to indicate that it would not provide a response and another did not respond at all. Of the seven companies that responded, the replies ranged from extensive commentary and responses to each question to more general comments and response to only some selected items.

In synthesizing the responses, the comments were paraphrased and any references to the company were deleted. No attribution of comments to individuals or companies is provided. It should also be noted that some respondents made clear that the response reflected their individual opinions and did not represent any formal position of the company. The synthesized responses to each question follow.

- *Do you consider the general concept of a vehicle-based system that recognizes a teen driver and provides driver feedback/vehicle performance adaptation to be a valuable idea? If no, why not?*

Six of the seven responding companies felt that the proposed system would be a valuable approach to improving teen driving and reducing crashes. Several indicated that it would be valuable in concert with other strategies, including graduated licensing, education, enforcement, more strictly monitored driving classes, and parental feedback (e.g., video recordings). The value of influencing safe driving habits and values early in the process while the driver is at a young age was noted. There were caveats regarding consumer acceptance and reliability such that parents can trust but also ensuring that users do not experience false warnings or faulty activations.

One respondent (noting he was expressing a personal view) was negative about the general approach of vehicle-based feedback to the teen driver. He was generally opposed to the position of using "expensive and complex technologies" and intrusive measures to address social and behavioral problems.

In summary, the response indicated strong, though not unanimous, industry support for the general concept. Concerns about consumer acceptance and system reliability will be important practical considerations.

- *Are there aspects of the system we have described that you see as impractical? We would like your thoughts on the practicality of each subsystem, as well as the overall integrated system. Please respond for each item below, and if you feel something is impractical, indicate why.*
- *Teen driver identification subsystem*

The planned approach of using a smart key with a specific teen driver key appears to be well accepted by the reviewers. It is seen as feasible and the Ford MyKey system was pointed to as a practical example currently available (though one person raised the question of whether the technology was patented). Some commented on the fact that it may be defeatable, if the teen borrows or copies another key. One reviewer more specifically stated that it is only practical where the parent is controlling the teen's vehicle usage and access to keys. Another noted that more sophisticated and less easily defeated technologies (face recognition, eye scan, voice recognition) might become available in high-end vehicles that already employ these technologies for other tasks. Reviewers noted there was a potential problem with two virtual keys being present in the vehicle and noted the need for one to be the primary key, with deferral to a teen key. It is also possible that a non-teen may use the teen key, so one reviewer suggested developing a method to override the vehicle system or make the driver aware that the teen key causes the vehicle to enable the teen system.

- *Seat belt detection and enhanced reminder subsystem*
- *Passenger presence subsystem*

The seat belt detection system and the passenger presence system are discussed together here, since the primary focus of comments for both had to do with the passengers, particularly rear seat passengers. The seat belt reminder system itself was generally seen as reasonable, although one commenter had a concern over the infotainment lockout, because it might encourage use of portable electronic devices. A number of respondents made comments regarding the detection of passengers and their belt use. They noted that current vehicles do not have such capability and that the detection of passengers, and differentiating them from cargo or child seats, would be difficult and expensive. Presence detection at each seating position was seen as a "great goal" but not immediately feasible. Some explicitly recognized the experimental nature of this aspect of the study. One respondent questioned why the proposed system was limited to the outboard seat positions and first two seat rows, and why adults were allowed to override the restriction.

The research plan for the present study had recognized that the state-of-the-art for current products made rear passenger presence detection difficult. However, the importance of multiple passengers as a crash risk factor for teen drivers made this an important priority for evaluation as part of a teen safety system.

- *Speed monitoring and feedback subsystem*

The speed monitoring subsystem was generally seen as feasible, but with a number of respondents expressing concerns about its potential accuracy. There were concerns about errors in the GPS database, the need for rapid updates when there are changes, and a means to deal with transient conditions such as road construction. A couple of respondents noted that there is sign video recognition technology and that this approach is being explored in Europe, but has less promise with U.S. sign practice.

A number of other concerns were expressed, including:

- A concern that a focus on speed, rather than on the difference in speed compared to prevailing traffic, might be counterproductive and needs to be carefully addressed. Holding the teen to the speed limit when surrounding traffic is faster could be a safety concern.
- The use of a fixed maximum speed might give the impression that only high speeds are dangerous; the maximum speed should be variable based on posted speed.
- Who would be responsible for assuring the accuracy of the posted speed database?
- What are the potential liability issues if the posted speed and system-identified speed are different? Could a driver cited for speeding argue that his vehicle told him his speed was within the law? If a driver believes a speed limit is lower than it actually is, could that pose a collision risk? Could discrepancies cause driver confusion/distraction?

Some respondents had questions about the specific rules (based on cautionary inputs) for the speed warning threshold. One felt that +15 mph was too high under any conditions, and that the maximum speed for a warning should be +10 mph. Another felt that school zones should be included in the system with a tight speed limit. Another felt that the matrix of speed-by-cautionary inputs was too complex. He argued that the 7x5 matrix in the plan be simplified to a 3x2 matrix (3 speeds: <30, 30-54, 55+; 2 inputs: no cautionary inputs or at least one).

- *Excessive maneuver subsystem*

There was no consistency in the comments on the excessive maneuver system. One respondent felt it was "reasonable and feasible" while another was concerned that an "aggressive" maneuver is not necessarily unsafe. Circumstances may require the maneuver and additional information (e.g., video) may be needed to understand it. We agree with the statement that some excessive maneuvers may be required, and for those cases the feedback may be unnecessary or inappropriate. However, this is viewed as similar to the occasional false alarm for other warning systems. The field evaluation provided the opportunity to see if the subsystem was nonetheless valuable and acceptable.

Various reviewers mentioned other concerns. One felt that without some form of reporting of these excessive maneuvers to an authority figure, the feedback may be ineffective or even counter-productive (if treated as a game). Another cautioned that it was important not to startle drivers when they are executing emergency maneuvers. Another did not like the icon because it looked too similar to a stability control icon.

Another comment dealt with the duration of the auditory signal. Because events may have durations of only a second or two, respondents felt that the suggested 10-second auditory signal was too long. However, it should be noted that the signal is not intended as a warning but as feedback that the driver engaged in an excessively severe maneuver. The research team's feeling was that the signal had to be long enough to be noted and salient after the event occurred. Field testing will provide further data on whether the duration is appropriate.

- *Cell phone use detection and mitigation subsystem*

The major point noted across respondents was a concern about whether cell phone use detection was feasible and the question of how this would be accomplished. This included concerns about discriminating driver phone use from passenger phone use, as well as discriminating various types of phone data transmissions. Another person noted that there are times when you want to allow cell phone use in the vehicle (emergency, parents contacting child). Some respondents pointed to an explicit need to detect and restrict text messaging. It was also noted that the Ford Sync system automatically mutes the infotainment system when a cell phone call is in process.

- *Driving context subsystem*

The driving context subsystem was generally seen as a positive, reasonable, and generally feasible. One respondent noted that while generally feasible, there may not be access to all the information available in all of the vehicles. Furthermore, the respondent noted that since "driving conditions" are inferences, drivers may be subject to errors. Another commented that it may be valuable to consider other contextual factors, such as traffic congestion or school zones. One reviewer had a specific concern about the inclusion of advisory speed limits. Since many drivers can maneuver curves at higher speeds than the posted advisory, this could result in mistrust or lack of confidence in road markings.

- *Total (integrated) system*

Only a few comments were received regarding the total system. One comment was that the system was complex, with a large number of components. As a result, there is a need to consider the potential for false warnings and for risks if some components fail. Another comment was that there should be fewer adaptation thresholds (reflecting this reviewer's comments on specific subsystems). Another noted that there should be consideration of whether the prototype interfaces are allowable under the Federal Motor Vehicle Safety Standards (FMVSS) or other regulations and voluntary agreements.

- *Are there additional functions that you would like to see included in a prototype safe teen car?*

The following additional functions were suggested:

- Drowsiness detection or attention alert system, since chronic sleep deprivation is an issue for teen drivers;
- Steering/lane keeping, headway maintenance;
- More general detection of inattention/distraction (not just technology use), although this is acknowledged to be hard to measure;
- Situation/event logging; technology is currently available to log notable events;
- Reporting functions, parental notification, video recording (like DriveCam), report cards; and
- Web site access to show accumulation of driving experience, what is needed to get to certain levels of driving capability.

One respondent specifically suggested including a reporting system as part of the study, and formally comparing feedback, reporting, and control conditions.

Although reporting strategies of various sorts are potentially valuable approaches to enhancing safety, they are explicitly outside the scope of the present project. The additional functions mentioned – lane keeping, headway maintenance, drowsiness detection, and general state of distraction/attention – all are relevant to teen driving safety. These in fact were considered by the project team in developing the recommended experimental system but were not included for this study because other functions were seen as higher priority and/or more practical to implement. The number of subsystems for this study needed to be limited to the higher priority functions in order to keep the system from being overly complex, intrusive, and expensive. We suggest that if the prototype STC is successful, some of these additional functions could be considered for future refinement.

- *Do you feel there would be good consumer interest and acceptance in this sort of vehicle feature? Can you suggest anything to improve consumer acceptance?*

There was a range of views on potential consumer interest and acceptance. Some indicated that they have evidence of positive consumer interest and acceptance. A respondent noted that parents of teen drivers would prefer feedback strategies to monitoring/reporting systems. Others indicated the system would appeal to a select subset of consumers, particularly parents seeking a safe car for their child to drive. Some indicated they were simply unsure of consumer interest. One expressed concern that many parents may not want an electronic "nanny" or "Big Brother" technology and that teens would resist limitations to their freedom. The overall impression from these responses is that there is no clear consensus on the likely degree of consumer interest or acceptance, although one company that offers a system with some of these capabilities was most enthusiastic about the degree of consumer interest.

In considering what can be done to improve consumer acceptance, a few comments were received. One suggestion was to have a traveling prototype vehicle visit high schools and colleges to demonstrate the safety technologies. Another suggested disseminating the results of this project (assuming the system successfully influences teen driving) to encourage interest among parents. Others noted that the details of the system will be critical, including a balance of incentives and disincentives. Also, the system may find acceptance as part of a broader package of teen driver strategies and partners, including DMVs, local communities, and more stricter training criteria. One respondent offered the specific suggestion of including a volunteer program where teens provide rides for older adults. This would not only provide a benefit for the older person, but would provide the teen with driving experience under conditions where they are likely to drive more safely, not be inclined to show off, and are more cognizant of older drivers and pedestrians.

3.2 Stakeholder demonstrations

A dedicated vehicle was instrumented with a prototype STC system and used for stakeholder demonstration. Stakeholder feedback was solicited in two venues. First, the prototype vehicle was demonstrated at the 2010 annual meeting of the Human Factors and Ergonomics Society in San Francisco. This professional society meeting is routinely attended by many industry and research experts in automotive design, driver behavior, and adolescent cognition and behavior. Subsequently, it was demonstrated at NHTSA headquarters in Washington, DC, for Department of Transportation personnel with interest and expertise in the topic. Feedback on the system was collected from those taking part in the demonstrations at each venue.

The STC demonstration system was installed in a 2009 Chevrolet Impala and was designed to implement the elements of the system in a configuration that appeared to be built into the vehicle. The factory-installed infotainment system was removed from the vehicle and replaced with a touch panel LCD display for STC visual feedback. Figure 3-1 shows this display integrated into the demonstration vehicle. Audio feedback was played via the factory-installed speakers.

In addition to the LCD display the demo vehicle included an additional display for use by the expert viewers of the system. Since many aspects of the STC system are not apparent to the driver, this additional display was developed to allow the experts taking part in the demo to see the status of the various vehicle subsystems. It allowed these experts to view how the system adapted operational criteria to aspects of driver behavior and situational factors in real time. Figure 3-2 shows this display. The display indicated whether the system was in teen or adult mode, what subsystem functions were operational, occupants detected and their belt use status, cell phone detection, lateral or longitudinal acceleration, environmental conditions, vehicle location, current speed, speed limit, and the current threshold for a speed violation warning.

Figure 3-1. STC demonstration vehicle visual feedback display integrated into the vehicle.

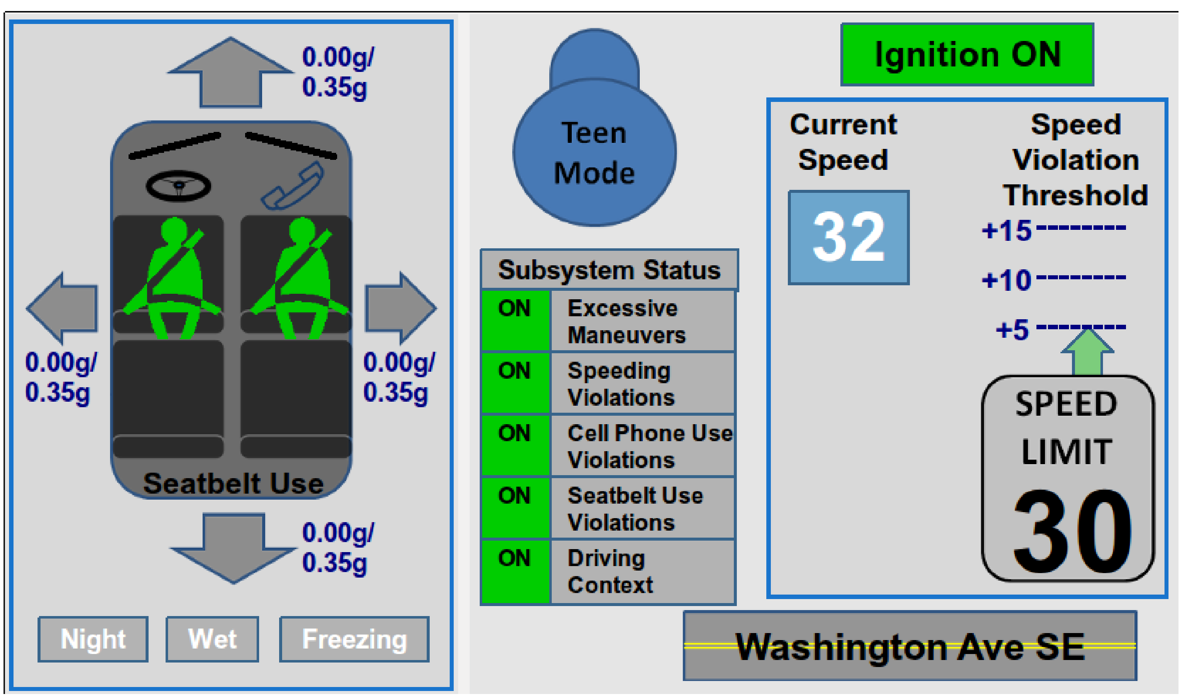


Figure 3-2. STC system status display used during demonstration drives.

A similar demo procedure was used at both the HFES and NHTSA sites. Interested participants signed up for demonstration drives, which were approximately 30 minutes in duration. On each drive, two participants accompanied a project team member who drove the vehicle. Participants were given a descriptive overview of the system and familiarized with the concepts and displays. The drive covered a variety of local roads and exercised all of the systems. The excessive maneuver criterion was intentionally reduced for purposes of the demo so that it would not be dangerous to trigger the driver feedback under traffic conditions. The system status display was active on a laptop computer during the drive, so that the participants could view and discuss it during the trip. Upon returning from the drive, the participants were queried about what features they liked or disliked about the system, what if anything they would change, whether they felt it would be effective, and whether they had any other comments or suggestions. A total of 35 HFES conference attendees took part over a three-day period. The NHTSA demo was a single day and approximately 12 people took the demo drive. Additional NHTSA staff attended a briefing on the system given prior to the scheduled drives.

Feedback from the participants in the demo drives was generally positive. They tended to feel the system was well designed and had good potential for effectiveness. Most of the comments dealt with the interface elements as opposed to system functionality. Minor modifications to the display were made in response to this feedback.

3.3 Subsystem pilot study

A pilot study of field test procedures was conducted to collect preliminary data on driver response to selected STC subsystems and to test the planned experimental methods for the subsequent full STC evaluation Thus, in this subsystem pilot, a teen's vehicle was equipped with either a Speed Management Subsystem, a Maneuver Subsystem or a Cell Phone Subsystem. Other subsystems such as driver ID and seat belt detection would be present in each of the three different subsystem evaluations.

This section presents a high-level overview of the methods, system features, and findings of the pilot. The system and methods were refined, but similar, in the full system evaluation, which is described in detail in Section 4. Appendix I: Evaluation of a Prototype Safer Teen Car: Conduct Evaluations of Subsystems provides details on the pilot efforts.

3.3.1 Overview of method

The STC system was adapted for implementation as a temporary system installed in study participants' own personal vehicles. Because the installation could not damage or otherwise interfere with use of the teen's vehicle, sensors and other system components had to be adapted to this constraint. For example, it was not possible to install piezoelectric strips under the fabric of the car seat, as was done for the demo vehicle. Likewise, we could not detect seat belt use by tapping into the vehicle safety control module, as was done for the demo vehicle. The main processing unit for the STC had to be limited in size and power and hidden from view. The STC visual display could not be integrated into the vehicle's dashboard, as in the demo car. Because of such challenges, the STC instrumentation for field-testing did not have the same degree of "original equipment" look-and-feel and the same degree of sensitivity or reliability as in the demo vehicle, and certainly differed from what an actual OEM system would be. However, the various work-arounds allowed for basic functionality of the subsystems while still being relatively easy to install and without requiring any marring of the participant's vehicle.

More detail on the instrumentation package used for field evaluation may be found in Section 4, which describes the full STC system evaluation. The final instrumentation and procedures found in that section reflect refinements based on the outcome of the pilot study. Complete documentation of the pilot study version was provided in a project interim report (Appendix I).

In overview, STC systems were installed in 28 teens' vehicles. Half of these participants were from a relatively rural portion of Minnesota and half from a suburban area in Maryland. The system was installed in each car for a period of four weeks. The first two weeks were a baseline stage, during which driving was monitored and data were collected but the STC did not provide feedback to the driver. The final two weeks were the treatment stage. In this stage, all subsystems were operational, but driver feedback was restricted to only certain subsystems for each participant. All 28 vehicles had the seat belt detection subsystem feedback active. Ten vehicles had speed monitoring system feedback, 10 had excessive maneuver system feedback, and 8 had cell phone detection system feedback. Within each of these conditions participants were exposed to the identification, sSeat belt, and passenger and context subsystems. This permitted an initial assessment of the sensors, operational aspects, displays, and effects of individual subsystems. Based on this, refinements were made for the full system evaluation.

Participants were accepted if they were 16 6to 18 years old with valid driver licenses obtained at least six months prior to agreeing to participate. At the time of system installation, participants were randomly assigned to one of the three subsystem condition groups. Participants were approximately distributed equally between rural and urban regions and by gender. Recruitment was approved by and consistent with Institutional Review Board Human Subjects Consent Protocol. While the system was being installed, teens and parents viewed PowerPoint presentations that familiarized them with the particular subsystems that would be installed in their particular vehicles. The presentation also included a brief overview of the interaction of the different thresholds of the subsystems.

Participants met with the research team three times after the initial STC installation. The first meeting occurred within five days of STC installation and was conducted to verify system functionality and data validity and to troubleshoot any initial issues encountered by participants. The second meeting occurred two weeks after STC installation and was conducted to initiate the two-week treatment phase by activating the STC feedback and vehicle adaptation functions. The final meeting was to conclude the study. During the final meeting the research team members removed the STC system from the teen vehicle and then debriefed and collected unstructured discussion information from teens and their parents about their STC experiences and potential issues. These discussions allowed participants to highlight different experiences with the system and parents to provide input about the system and its use. Teens received $200 and parents received $50 as an incentive for their participation.

The study collected a range of objective vehicle and driver data from the STC. Dependent variables included seat belt detection frequency, passenger presence detection, speeding time, speeding exceedance, and G-force threshold. Subjective usability information was also collected from the unstructured discussions after the completion of data collection.

3.3.2 Summary of subsystem pilot study findings

Only selected findings from the subsystem pilot study are presented in the current report since the primary goal was a pilot for the full STC system evaluation. Note that a comparison of subsystem findings to the subsequent full system findings is not advisable since subsystem users, by definition, were not exposed to a fully functional design. Additional details and results for this pilot study are found in Appendix I: Evaluation of a Prototype Safer Teen Car: Conduct Evaluations of Subsystems.

The findings from the pilot were of two general sorts: effects of the system on teen driver behavior/acceptance and the adequacy of the instrumentation and methods used. Selected findings on behavior and acceptance will be presented first. However, given the small number of participants under each subsystem condition, as well as reliability or other issues with some of the subsystems, relatively few comparisons were found to be of statistical significance. This was anticipated and the primary function of the pilot was to uncover any concerns that would need to be addressed prior to the full system evaluation.

Key findings regarding teen driver and parent responses to STC subsystems were:

- The speed monitoring subsystem led to a reduction in the number of speeding miles for the >5-10 mph over the speed limit category during the treatment stage.
- The seat belt monitoring subsystem led to an increase in the number of miles traveled while the driver was belted during the treatment stage.
- No significant effect of stage was found for the excessive maneuver subsystem or cell phone use detection subsystem.
- Subjectively, teens from both locations found the subsystems to be useful, but Maryland teens were neutral towards system satisfaction and Minnesota teens were slightly unsatisfied. This may have been due to the problems experienced with reliability, false alarms, and battery issues.
- Parents found the systems to be both useful and satisfying.
- In both Minnesota and Maryland, the majority of teens agreed that the STC system they experienced improved safety. However from those that responded to the question, only in Minnesota did most (75%) teens agree that the system made them a better driver; only 33 percent of Maryland participants agreed with this.
- Eighty percent of teen participants in both Maryland and Minnesota who experienced the speed subsystem reported that the STC "probably" or "definitely" changed the way they drive. However, the two sites differed substantially in response to the excessive maneuver and cell phone systems. Minnesota participants reported changing the way they drive with these subsystems, but most Maryland participants did not. The performance results indicated differences between the two locations with respect to excessive maneuvers, cell phone, and speeding exceedance. Generally, the Minnesota teens had lower mean occurrence rates when compared to Maryland teens. The reasons for these differences are not known, although there were greater problems with the cell phone detection system in Maryland, as well as differences between sites in driving environments.
- Somewhat in contrast to the teen subjective response, from parents that responded, more parents in Maryland (83%) reported "yes" when asked whether they would recommend the STC system to other parents. In Minnesota, 33 percent said "yes," while the majority (53%) said "yes, but with reservations."

Based on this pilot, certain modifications to the STC instrumentation or procedures, as adapted for non-intrusive temporary installation in participant vehicles for field evaluation, were identified. These included:

- Passenger presence subsystem: Reliable detection of front and rear seat passengers was a challenge. As implemented for the pilot, the system was based on floor-mounted passive infrared (PIR) sensors to detect the heat signature of passenger leg motion. Detection with this system was not adequately reliable for a number of reasons, including the frequency of unsecured moving objects on the floor of teens' vehicles and the tendency of many passengers to have minimal leg movement. Based on this, a different sensing technology, using encapsulated flex switches was developed for the full system evaluation.
- Excessive maneuver subsystem: Some participants suggested the excessive maneuver warning was directionally ambiguous and the tone was excessive in length. However, participants also noted that they drove more conservatively due to the feedback from this system. However, the pilot study performance data offer limited objective results to support the participants' conclusions. To increase understanding and awareness of the excessive maneuver subsystem, an example of both lateral and longitudinal maneuvers that may trigger the warning was provided verbally to the teen drivers during the introduction to the full STC study. These examples included excessive acceleration, braking, and cornering. No other changes were made.
- Cell phone use detection subsystem: The cell phone use detection system was not very reliable. Although reliability was not directly measured it was estimated to be around 35 percent. In some locations, false alarms were frequent and a source of driver annoyance and poor system acceptance. Following the pilot, the study team reinvestigated recent products and technologies that might improve reliability. Some emerging products and approaches appear to have promise, but none were sufficiently mature. None were found that would be reliable and practical in a moving vehicle environment. Therefore, the cell phone subsystem was dropped from the full system evaluation.
- System power requirements: During the subsystem evaluation phase, it was determined that participants that drove infrequently or only a few miles a day did not run their vehicle long enough to maintain a sufficient charge on their batteries. A battery charger was provided to participants to keep their battery fully charged while not being driven. This addition, however, required a change in the method used to determine whether the vehicle was powered on. At the subsystem evaluation phase, the system measured the battery voltage to determine whether the vehicle was running; a running vehicle has a higher battery voltage than one that is not. The addition of a battery charger (that puts out a high voltage) led to incorrect identification of when a vehicle is running. In order to prevent this, a separate wire was connected between the STC system and an ignition fuse.

4 Full Evaluation of the Safer Teen Car

The pilot subsystem evaluation provided valuable insight and feedback with regard to the subsystems' impact on teen driver behavior. The pilot subsystem evaluation indicated that during the time the subsystems were activated the number of speeding miles was reduced and the seat belt compliance rates increased. However, no differences were found for the excessive maneuver subsystem between the baseline and treatment stages. In addition, the cell phone subsystem suffered from reliability issues. Overall, these findings indicate that some of the subsystems showed a positive effect on teen driver behavior during the short-term subsystem evaluation. The next phase of the research effort investigated integration of all the subsystems into a unified system (i.e., full STC) and presented over a longer duration (10 weeks).

To measure the extent to which the STC changed teen driver behavior, the evaluation included three specific data collection stages over a 10-week time period. First, there was a 2-week baseline stage in which the STC did not provide feedback to teens or adapt vehicle functions. The baseline stage was then followed by a 6-week treatment stage during which time all STC subsystems were activated and provided feedback. The treatment stage was split into three 2-week periods: Immediate, short-term, and long-term treatment. The final stage that followed was a 2-week post-treatment transfer stage where the STC was turned off.

The evaluation included all STC subsystems (i.e., passenger presence, seat belt detection, driving context, excessive maneuver and feedback, and speed monitoring and feedback) with the exception of the cell phone use detection subsystem that was dropped due to the lack of reliability under field conditions. Driving behavior data were collected throughout each of the three stages. This allowed for comparisons between the stages that would identify the extent to which the STC contributed to changes in driver behavior, the extent to which teens adapted to the continued use of the STC, and the extent to which there were any carry over-effects after the STC was deactivated. At the end of the study each teen driver, accompanied by one parent, participated in unstructured discussions intended to understand their specific experiences and impressions of the STC during the research effort. Specifically, this activity provided insight into teen and parent experiences as well as insight regarding STC components they felt would benefit from further redesign efforts. The remainder of the current section of this report summarizes the full STC evaluation including research hypotheses, field study methods, dependent variables and statistical analyses, results, and discussion.

4.1 Research questions

A number of research questions were posed based on the extended data collection period afforded by the 10-week field study. The Task 3 report details the research hypotheses and statistical analyses for the Full STC field test. Briefly, the key research questions were:

- Will teens reduce their rate of risky driving behaviors after they have been exposed to the STC? The influence of the STC was predicted to impact teen driving behavior between the baseline stage and immediate stage by reducing the number of speeding exceedance violations in all speed groups, reducing the number of excessive maneuvers in all groups, and increasing seat belt compliance upon activation of the STC.
- How will teens adapt their behaviors in response to use of the STC over time? There is a need to identify teen driver performance as they are continually exposed to the STC. It is hypothesized that the STC will enhance teen driver safety upon initial use, but teens may adapt in unintended ways upon long term use. Comparisons between immediate and long-term stages could reveal behavioral adaptations.
- When the STC is no longer used by teens will the rate of risky driving behaviors return to pre-STC levels or will teens continue to exhibit a change in the rate of risky driving behaviors? The influence of STC after its deactivation was expected to transfer in a positive way such that teens continued safe teen behaviors. Whether this occurs or not was explored

through the comparisons between the initial baseline stage and the final transfer stage of the research effort.

- How do teen drivers and their parents subjectively view the subsystems and how "acceptable" is the system? Finally, participants' unstructured opinions of the STC were of value to identify any positive or negative aspects not apparent in the performance data.

4.2 Field study method for Full STC Evaluation

4.2.1 Participants

Thirty teen drivers (17 male and 13 female) 16 to18 years old participated in the field evaluation, drawn from sites in Minnesota and Maryland. In Minnesota a recruitment agency was used and recruited participants using flyers, Craigslist.com, and word of mouth (Appendix A). In Maryland, recruitment was achieved via Facebook.com, Craigslist.com, and Westat's Web site. As part of the recruitment requirements teens were sought with a minimum of 6 months of driving experience.

To identify potential differences based on geographic location, teens were recruited from both the suburban/rural areas of Minneapolis/St. Paul metropolitan area (e.g., Washington, Hennepin, and Ramsey counties) and also from suburban/urban areas of Maryland (e.g., Montgomery County). It is important to note that the graduated driver licensing (GDL) requirements are different between the two states. For example, in Minnesota the nighttime driving restrictions are eliminated after 6 months of provisional licensure. Furthermore, passenger restrictions are also removed after 6 months of "clean" driving that allows teen drivers up to three passengers in the vehicle under 20 years old (IIHS, 2011). The Maryland GDL requirements mandate that teens are to be 16.5 years old before obtaining a provisional license. Additional limitations for Maryland teens include passenger restrictions such that no passengers younger than 18 are allowed for the first five months of provisional licensure. Furthermore, the nighttime restrictions are in place for a longer period of time as Maryland teens are restricted from driving between midnight and 5 a.m. until at least 18 years old (IIHS, 2011). The restrictions for both states can be imposed for longer durations and are dependent on teen compliance.. These differences may contribute to potential differences identified in comparisons between the two locations and their contribution is noted where necessary.

The mean age of teen drivers was similar between males and females and between testing locations (see Table 4-1). Males reported lower estimated weekly mileage compared to females and Minnesota teens reported higher estimated weekly mileage compared to their counterparts (see Table 4-1). Overall, 22 teens indicated they drove every day while five indicated they drove five or six days per week and three indicated they drove three to five days per week. Twenty-five of the teens drove passenger cars, 3 drove SUVs, and the remaining 2 teens drove pickup trucks.

Table 4-1. Teen driver age, licensure duration, and estimated weekly mileage.

	Male		Female		Maryland		Minnesota	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	17.5	0.2	17.5	0.3	17.6	0.2	17.4	0.3
Licensure (Months)	10.8	3.8	11.0	4.7	8.8	2.1	13.1	4.5
Miles per Week	123.4	153.7	148.2	155.9	96.8	123.2	180	177.9

4.2.2 Apparatus

The following provides a brief summary of the STC subsystems of interest; however, a full description of their components can be found in Appendix H: Evaluation of a Prototype Safer Teen Car: Determine Enabling Technologies That Meet the Functional and Interface Specifications.

Teen driver identification subsystem: Each parent (or sibling who used the vehicle) was provided with a card that contained a passive RFID tag and was instructed to keep the card on his or her person throughout the study. When the passive RFID card was present in the vehicle the TDIS presented a selection screen that allowed parents to deactivate the STC.

Passenger presence subsystem: Pressure-sensitive tape switches were embedded in a set of seat covers on the front and rear passenger seats that allowed the STC to determine when a passenger occupied the seat. Switches were distributed on the seat pan and back of seats to help avoid false occupant detections from heavy items such as bags.

Seat belt detection and enhanced reminder subsystem: Identification of seat belt compliance was accomplished using reed switch magnets attached to the seat belt stanchions at each of the four seating locations. There were two phases of audible warnings for the driver seat position. A *reminder phase* ("Buckle seat belt.") that occurred if the driver buckle was not fastened when the car was stationary and a *motivator phase* ("Driver, buckle seat belt.") that cycled every 30 seconds if the driver remained unbuckled while the car was in motion. The two audible warnings were paired with a visual icon and text stating "Driver buckle seat belt." There was a unique audible for the front passenger, driver-side rear passenger, and passenger-side rear passenger seat positions (e.g., "Driver-side rear passenger, buckle seat belt" for the passenger position behind the driver). The passenger warnings were accompanied by a visual icon and text stating, "Passenger buckle seat belt."

Driving context subsystem: Crash risk for teen drivers increases during nighttime driving conditions. The DCS adjusted STC thresholds to account for this known risk. A nighttime condition was determined by comparing STC clock time to known sunrise and sunset times. When the system identified a nighttime condition, the DCS reduced thresholds for both the EMFS and SMFS subsystems.

Excessive maneuver and feedback subsystem: The EMFS provided feedback to drivers when a vehicle maneuver (i.e., lateral and longitudinal acceleration) exceeded a critical threshold. The unmodified threshold was .5g (~4.9m/s^2, which is equal to a change in velocity equal to approximately 11 mph in 1 second). The threshold value was modified by the status of the DCS, PPS, SBDRS, and the speed limit of the roadway traveled. For example, the threshold decreased for the excessive maneuver warning at night, if there was three or more passengers present, or if the driver or a passenger were not buckled. The threshold also decreased with higher the speed limits. The input from the subsystems was additive- such that when the subsystems detected co-occurring events the threshold was further reduced. These additional threshold parameters took into account the passenger presence and speeding with respect to excessive maneuvers. Specifically, teen drivers are at increased risk when teen passengers are present and show elevated excessive maneuvers compared to adult passengers (Simons-Morton et al, 2011).The maneuver warning consisted of a visual icon synchronized with a ten-second tone.

Speed monitoring and feedback subsystem: The SMFS provided feedback to drivers when the vehicle speed was greater than a set threshold (based on the posted speed limit). If participants exceeded the speed limit by 2 mph a mild speed warning of a 1-second auditory tone was presented. If participants increased their speeds and drove to a second threshold (2 mph to 15 mph above the speed limit, based on other subsystem inputs and speed limits), a second strong speed warning was presented to drivers and consisted of the phrase "Speeding violation" followed by a one-second buzz. A third speed warning occurred at speeds over 80 mph and consisted of the phrase "Slow down now" followed by a longer buzz. During the strong speed warning a visual icon (i.e., speed limit sign) changed from white to red. The SMFS threshold for the strong warning was modified by the status of the SBDR, the DCS, and the speed limit of the roadway. At higher speed limits, with no other subsystem inputs, the strong warning was set at a higher threshold than at lower speed limits. This allowed teens to moderate speed with respect to traffic, but not engage in excessive speeding. The input from the other subsystems were additive. When the subsystems detected co-occurring events the threshold for the strong speed warning was further reduced.

System adaptation: A unique and integral component of the STC was the ability for the system to adapt and modify warning thresholds based on contextual parameters. When the STC was active it monitored speed information, passenger presence, seat belt use, driving context (e.g., day or night) and excessive maneuvers continuously. Real-time alerts were provided to the teens based on a number of complex interactions coordinated and accounted for by each subsystem component. Threshold alert levels were established for each of the subsystems in addition to complex additive interactions between the subsystems as part of the adaptive system architecture. For example, a teen driver driving alone during the daytime in a 55 mph zone would receive a strong speed warning at 70 mph (or 15 mph above the limit). However, if the teen had three unbuckled passengers in the vehicle and was also driving the vehicle at night a strong speed warning occurred at 57 mph instead because of the other risk factors (e.g., unbuckled passengers and night driving). Contextual information from all of the subsystems and potential influences by each of them were integrated as part of the adaptive strategy of the STC. An example of thresholds and subsystem interactions for speed alerts is provided in Appendix B.

Driver interface Summary: The primary physical driver interface design for the combined STC subsystems consisted of the auditory and visual displays for the Seat Belt Detection and Enhanced Reminder Subsystem, the Excessive Maneuver and Feedback Subsystem, and the Speed Monitoring and Feedback Subsystem. The driver may have become aware from time to time of other subsystems without displays (e.g., Driver Context Subsystem). This would result from subsystem interactions such as a decreasing speed limit threshold resulting from the Driving Context and/or Passenger Presence Subsystem inputs.

4.2.3 Procedure

When parent and teen participants arrived at the University of Minnesota or Westat for the STC installation they completed informed consent forms (Appendix C: Parent/Guardian Consent Form) and assent forms (Appendix D: Teen Assent Form). The STCs were then installed into their vehicles, which took about three hours. During the installation period teens and parents were introduced to the STC functions through a PowerPoint presentation that reviewed each of the major subsystems and the adaptation features. The overview allowed participants to become familiar with the STC system and to recognize and understand the different feedback mechanisms. The review included pictures of the subsystems and visible components within the vehicle. The auditory and visual feedback associated with some of the subsystems was provided so that participants could understand what the STC could display and why it was being displayed. Furthermore, examples were provided to participants (e.g., adaptation of speeding subsystem) regarding the interaction of the different threshold levels for the subsystems. At the end of the presentation and STC installation participants were instructed to drive as they normally would and to interact with the STC in a manner in which they felt comfortable. This allowed the teen drivers to interact with the STC feedback and vehicle adaptations in an unconstrained manner thus allowing natural driver behavioral changes over time.

There were multiple stages within the 10-week evaluation effort. The initial baseline stage lasted 2 weeks and started immediately after the STC installation. During the baseline stage the STC did not provide feedback but collected driver performance data to identify normative driving behaviors. The treatment stage was divided into three separate 2-week periods representing immediate, short-term, and long-term exposure to the STC. The comparisons of driving performance over these separate treatment stages provided insight into the influence of the STC feedback and vehicle adaptations over time in addition to STC acceptance over time. The evaluation concluded with a 2-week transfer stage in which teen drivers did not receive STC feedback or vehicle adaptations. The transfer stage allowed for the examination any carry-over effects from STC use after the system was turned off.

Throughout the evaluation participants met with the research team multiple times. The first meeting occurred within 5 days of STC installation and was conducted to verify system functionality/data validity and troubleshoot any initial issues encountered by participants. The second meeting occurred two weeks after STC installation to initiate the treatment phase by activating the STC feedback and vehicle adaptation functions. Telephone check-ins occurred shortly after initiating the STC and around the third week of treatment the treatment period (i.e., week 6 in the study overall) to identify any issues or potential hardware/software problems. Another onsite meeting occurred at the eighth week to turn off the STC system and initiate the transfer stage of the experiment. A final meeting was scheduled at the 10th week to conclude the study. During the final meeting the research team members uninstalled the STC system from the teen's vehicle and collected unstructured discussion information from teens and their parents about their histories and STC experiences. These discussions allowed participants to highlight different experiences with the system and also gather parental input about the system and its use. During the entire 10-week period teens received combined payments totaling $200 each and parents received $50 each as incentive for their participation.

4.2.4 Dependent variables and statistical analyses

Two types of data were obtained from this study; the first was objective vehicle and driver data while the second was usability data collected using questions and unstructured discussions. The following sections summarize each of the data measures.

4.2.4.1 Vehicle and driver data

The following data were collected directly from the STC and served as the basis for the derived data:

- Latitude and longitude coordinates of vehicle position;
- Distance driven (miles);
- Posted speed limit (mph);

- Vehicle speed (kph);
- X and Y (m/s^2);
- Occupancy (the driver and up to 3 passengers);
- Radio frequency identification (RFID) card presence (or adult passenger);
- Seat belt activation;
- Time of day; and
- Count of system warnings.

The following measures were derived from the STC data identified above and served as the dependent variables for the evaluation. Measures of driver performance are reported as averages per stage.

- Seat belt detection frequency – The percentage of miles driven while the seat belt was fastened for each occupied seating position.
- Passenger presence detection – The percent of miles driven when the PPD sensors were triggered. Each seat position was reported separately.
- Speeding exceedance – The percentage of miles the vehicle was driven at speeds greater than the speed limit within each of four speed bins (i.e., between 1 and 5 mph greater than the speed limit, between 6 and 10 mph greater than the speed limit; between 11 and 15 mph greater than the speed limit, and greater than 15 mph greater than the speed limit). SE was only available for road segments represented within the NAVTEQ database with a speed limit. Speed data for road segments without a precise speed limit were excluded from this measure.
- G-force threshold exceedance (G) – Positive (left) and negative (right) lateral accelerations as well as positive (acceleration) and negative (deceleration) longitudinal accelerations were recorded. The percentage of miles the vehicle was driven within each of four bins of acceleration (i.e., between 2 m/s^2 and 3 m/s^2, between 3 m/s^2 and 4 m/s^2, between 4 m/s^2 and 5 m/s^2, and in exceedance of 5 m/s^2). For reference, 1 G is equal to 9.82 m/s^2.
- System warning count – For each stage (i.e., baseline, each of three treatment stages, and the transfer stage) a count was established to identify the issue of a warning. For each subsystem, the count was summed and then divided by the total miles traveled as a measure of the warning frequency per mile.

4.2.4.2 Usability and unstructured discussion data

The results of a transport telematic acceptance assessment, a questionnaire designed by van der Laan, Heino, and de Waard, 1996, and usability assessments are reported. These two metrics gauge users' perceived satisfaction and usefulness of the STC system. The results of this assessment are identified as Transport and Telematic Acceptance Assessment in the results section of this report. In this assessment, parents and teens were presented with a series of questions that assessed their perceptions of trust in STC relative to factors such as safety reliability, and their confidence in the system (identified as "Trust discussions" in the results section of this report). Both parents and teens discussed general reactions to the STC and potential improvements (identified as teen and parent attitudes and safety in the results section of this report). Parents also discussed their impressions of the system, provided recommendations for the STC and addressed if they would pay for a STC system and how much, and whether the STC was an invasion of privacy (identified as parent unstructured discussions in the Results section of this report). Common themes were grouped together for both teens and parents.

4.2.5 Statistical analyses

Each dependent variable for vehicle and driver data (i.e., derived variable) was analyzed using a 5 x 2 x 2 mixed model analysis of variance (ANOVA) model with stage (baseline, immediate treatment, short term treatment, long term treatment, and transfer) as a within-subject variable and location (Minnesota, Maryland) and time (daytime, nighttime) as between-subject variables. A difference was considered statistically significant at or below a *p* value of .05. If the between subjects factor was not statistically significant the analysis was then collapsed across those groups in an effort to control for the variable and also provide the remaining analysis with increased power. Table 4-2 is a list of the primary and follow-up comparisons and associated reporting data that are possible for each dependent variable using the example of "0-5 mph over the speed limit" as the dependent variable. It is also noted that paired comparisons were conducted to isolate differences within a main effect. Due to the increased number of comparisons, all post hoc analyses (t-tests) were made using a Bonferroni alpha correction. Post hoc analyses, when conducted for the stage comparisons, used a series of planned comparison t-tests. These comparisons aligned with the research questions and hypotheses. The comparisons included:

1. Baseline stage compared to the immediate stage. This identified any immediate effects of the subsystem during the initial two weeks the STC was functioning.
2. Immediate stage compared to short-term stage. This comparison was conducted to identify any subtle changes as participants acclimated to the STC.
3. Short-term compared to long-term stage. This was conducted to identify any continued behavioral adaptation benefits or detriments of continued STC use.
4. Immediate compared to long-term stage. Conducted to identify any differences in immediate versus long-term STC use.
5. Long-term compared to transfer. This was conducted to see any positive or negative behavioral adaptations and carry over effects.
6. Finally the baseline stage was compared to the transfer stage. Again, identification of any differences both positively and negatively between the start and finish of the research effort.

Additional analyses were conducted to investigate the effects of vehicle occupancy (driver alone versus driver with one or more passengers).

Table 4-2. Example analysis reporting table.

Speed Zone	Factor	*df*	F or t	*p-value*	M^1	M^2
>0-5 mph >SL	Stage x Time x Location					
	Stage x Location					
	Time x Location					
	Stage x Time					
	Stage					
	Time					
	Location					

4.3 Results

An overview of the set of analyses of variance conducted on the field evaluation data, along with an indication of which factors were found to be statistically significant in each analysis, is shown in Table 4-3. Further discussion of the statistically significant findings is provided in the sections that follow.

4.3.1 Vehicle and driver data

Five teens did not complete the entire 10-week study; one teen vehicle had mechanical issues and discontinued participation mid-way through the study, one system had consistent hardware failures such that removal of the system was required, and three teens requested early removal of the system that resulted in gaps in certain sections of the treatment and transfer data collection periods. The hardware failures appeared to be combination of a display issue in addition to instances of system tampering where power cables or cables were removed from the system. The data for these individuals is noted or removed within the analysis section where appropriate. Data sets were not separated based on gender and were collapsed to provide additional power for statistical tests.

Prior to statistical analyses the entire data set was reviewed to identify anomalies (e.g., outliers due to missing data or hardware/software data collection failures) and, in those instances, the data were removed from the data set.

Data analyses were conducted on miles driven by teens as identified by the absence of an RFID marker in the data. An RFID card was detected for 15.7 percent of the total mileage (17.8% of the GPS mileage) and varied between participants (see e.g., Appendix E). If an RFID card was present but teen mode was selected on the TDIS, the data were still excluded from the analysis because the presence of RFID card and the absence of adult mode selection did not provide enough information to discriminate if a teen was driving with an adult, an adult was driving in teen mode, or a teen was driving without an adult but the RFID card was still present. An assumption was made that data without any RFID card contained valid teen driving data and were used for the analysis.

Valid GPS information allowed the STC to identify speed limit zones by querying the onboard NAVTEQ map database. When the system database did not provide a speed limit for a particular section of roadway or if there was a speed range (e.g., no absolute speed limit defined) then the speed subsystem did not provide feedback to the teen driver. For teen drivers the speed limit was known for 66 percent (25,216 miles) of all recorded miles driven by teens (38,125 miles). The number of miles travelled by teens where the speed limit was not known was higher in Minnesota (6,996 miles) compared to Maryland (5,913 miles). Instances of GPS signal loss or GPS signal without map data occurred that impacted the speed feedback subsystem. If speed limit data were not available, the related variable information was not calculated for these sections of data and subsequently was not used in the overall analyses. The mileage driven by teens during the day or night is reported in Appendix F: Vehicle Miles Traveled Night and Day by Teens.

Only significant results for each dependent variable within each subsystem are presented in the following sections.

Table 4-3. Overview of outcomes of analyses of variance.

Variable	Occupancy	Factor						
		Stage	Time	Location	SxT	SxL	TxL	SxTxL
SDF	Driver				[1]			[1]
SDF	Front passenger	[1]						
SDF	Rear passenger (driver side)							
SDF	Rear passenger (passenger side)	*	*					
PPD	Driver							
PPD	Front passenger				[1]			[1]
PPD	Rear passenger (driver side)							
PPD	Rear passenger (passenger side)							
SE >0-5	Alone						*	
SE >0-5	Passengers							
SE >5-10	Alone	*	*			*		
SE >5-10	Passengers		[1]					
SE >10-15	Alone	*	*			*		
SE >10-15	Passengers	*	*					
SE>15	Alone							
SE>15	Passengers							
G 2-3m/s^2	Alone		*					
G 2-3m/s^2	Passengers	[1]	*					
G 3-4m/s^2	Alone							
G 3-4m/s^2	Passengers		[1]					
G 4-5m/s^2	Alone					[1]		
G 4-5m/s^2	Passengers	*				[1]	[1]	[1]
G 5+m/s^2	Alone							[1]
G 5+m/s^2	Passengers							

SDF = seat belt use detection; PPD = passenger presence detection; SE = speed limit exceedance range; G = maximum lateral or longitudinal G-force range.
* $p<0.05$; [1] $p<0.10$

4.3.1.1 Speed management subsystem

Speeding Exceedance, Driver Alone
As anticipated all participants had instances where GPS information was not available or the speed information was unavailable due to an unmapped speed zone. However, one participant from Minnesota had a GPS failure that lead to complete signal loss during the baseline stage. The hardware was reset for this participant upon identifying the issue and participation in the baseline stage was extended. Similarly, Maryland had three participants who experienced complete signal loss at some point throughout the data collection period. Upon identification the hardware was either reset or replaced and participation continued without an extension. For one of the three Maryland teens complete data loss occurred for the long term stage resulting in no speed information for the analysis. The data were removed from the speed analysis, but were used in other analyses.

Results of the speed management subsystem analyses can be found in Table 4-4. There was no significant three-way interaction for the ANOVA (e.g., stage x location x time). Follow up comparisons indicated a significant effect of decrease in the mean percentage of speeding miles from the baseline to the immediate stage for the >5-10mph> speed limit (SL) range (*M* = 14.7% versus *M* = 10.8%). A statistically significant difference was also found between the long-term and transfer stages for the >10-15mph > SL, with a significant increase in percentage of speeding miles (*M* = 2.3% versus 4.3%). Results also indicated that teens incurred fewer speeding miles during nighttime conditions compared to daytime conditions for the >5-10mph> SL (*M*= 14.9% versus *M* = 11.3%) and the >10-15mph > SL speed zones (*M* = 4.5% versus 2.3% , respectively). No additional statistical differences were observed in the driver alone speeding exceedance analyses.

Table 4-4. Speed management subsystem driver alone (percentage of speeding miles for speeding exceedance).

Speed Zone	Variables	df	F or t	p-value	Partial Eta Squared	Comparisons	
>0-5mph>SL	Time of Day x Location	(1, 14)	5.5	0.03	0.29	*	
>5-10 mph>SL	Stage x Location	(4, 56)	2.8	0.03	0.57	*	
	[1]Stage	(4, 56)	5.8	0.01	0.30	-	
		(28)	3.3	0.01		14.7% (Baseline)	10.8% (Immediate)
	Time of Day	(1, 14)	7.1	0.02	0.34	14.9% (Daytime)	11.3% (Nighttime)
>10-15mph>SL	Stage x Location	(4, 56)	2.8	0.05	0.16	*	
	Time of Day	(1, 14)	14.8	0.02	0.51	4.5% (Daytime)	2.3% (Nighttime)
	[1]Stage	(4, 56)	5.5	0.01	0.28	-	
		(18)	-4.5	<0.01		2.3% (Long Term)	4.3% (Transfer)

*Post hoc comparisons did not yield statistically significant differences. [1] Follow up test significant.

Speeding Exceedance, Driver with Passenger(s)
A significant main effect was found for the 10 to 15mph above the speed limit speed zone (>10-15mph >SL) where the percentage of miles decreased from the baseline (*M* = 15.9%) to the immediate (*M* = 6.3%) stage (see Table 4-5). Within this speed zone teen drivers had significantly fewer speeding miles during nighttime compared to daytime conditions. No additional differences were found within the speed management system analyses.

Table 4-5. Speed management subsystem driver with passengers (percentage of speeding miles for speeding exceedance).

Speed Zone	Variables	*df*	F or *t*	*p-value*	*Partial Eta Squared*	*Comparisons*	
>10-15mph>SL	Time of Day	(1, 14)	14.7	< 0.02	0.51	1.3% (Daytime)	0.6% (Nighttime)
	[1]Stage	(4, 56)	5.5	0.02	0.18	-	
		(28)	3.32	0.03		15.9% (Baseline)	6.3% (Immediate)

[1] Follow up test significant.

4.3.1.2 Excessive maneuver subsystem

G-Force Threshold Exceedance, Driver Alone
There was a significant main effect for time for the 2-3 m/s^2 longitudinal negative (e.g., slowing) dependent variable. Results indicate significantly fewer miles driven within this range during nighttime (*M* = 1.0%) compared to daytime (*M* = 1.3%) conditions (see Table 4-6). No additional differences were found within the G-Force Threshold Exceedance excessive maneuver subsystem driver alone analyses.

Table 4-6. Maneuver subsystem driver alone (percentage miles of excessive maneuvers).

Maneuver Type	Maneuver Level	Variables	*df*	F or *t*	*p-value*	*Partial Eta Squared*	*Comparisons*	
Longitudinal Negative	2-3 m/s^2	Time of Day	(1, 14)	5.5	0.03	0.39	1.3% (Daytime)	1.0% (Nighttime)

G-Force Threshold Exceedance, Drivers with Passenger(s)
Results (See Table 4-7) indicated a main effect for the 4-5m/s^2 lateral negative (e.g., right turn) excessive maneuver range dependent variable where the percentage of miles in this exceedance zone decreased from the baseline to the immediate treatment stage. There was a significant main effect for the 2-3 m/s^2 longitudinal negative (e.g., slowing) dependent variable between day and night, where percentage of miles was higher for daytime when compared to nighttime (*M* = 0.5% versus *M* = 0.4%, respectively). Specifically, there were fewer miles traveled within this range during nighttime as compared to daytime conditions. No additional significant differences were found within the G-force threshold exceedance analyses conducted on driver-with-passenger data.

Table 4-7. Maneuver subsystem drivers with passengers (percentage of miles of excessive maneuvers).

Maneuver Type	Maneuver Level	Variables	*Df*	F or *t*	*p-value*	*Partial Eta Squared*	*Comparisons*	
Lateral Negative	4-5m/s^2	[1]Stage	(4, 76)	5.1	0.01	0.21	-	
			(29)	2.6	0.01		0.01% (Baseline)	0.0008% (Immediate)
Longitudinal Negative	2-3 m/s^2	Time of Day	(4, 56)	5.5	0.01	0.23	0.5% (Day)	0.4% (Night)

[1] Follow up test significant.

4.3.1.3 Seat belt detection subsystem

The frequency of seat belt use was collected for the four vehicle seating positions (e.g., driver, passenger, rear driver side passenger, rear right side passenger). Daytime seat belt compliance for rear passenger side was significantly higher (84.7%) compared to nighttime (69%) ($F[1, 14] = 10.9$, $p = 0.05$). There was also a main effect for stage ($t(14) = 3.2$, $p = 0.006$) for the rear passenger side in which seat belt compliance increased from the immediate (67.9%) to the short-term treatment stage (84.4%). No additional significant differences were observed within the seat belt detection subsystem analyses.

4.3.1.4 Passenger presence detection

No significant main effects or interactions were observed within the passenger presence analyses.

4.4 Usability and unstructured discussion data

4.4.1 Transport telemetric acceptance assessment

The results of a transport telemetric acceptance assessment (van der Laan, Heino, & de Waard, 1996) provided to teens and parents in Maryland indicated that teens perceived the system to be useful but somewhat dissatisfying (see Figure 4-1). Teens commented the STC exhibited some reliability, false alarm, and battery drainage issues that influenced their perceived satisfaction. Maryland parents found the STC both useful and satisfying and commented that despite the issues that arose, the STC was useful for new drivers because it helped create awareness of “good” driving behaviors.

Maryland teens found the STC system to be more useful and more satisfying than their Minnesota counterparts (see Figure 4-2). Minnesota teens also noted the same STC reliability, false alarm, and battery drainage issues. Overall, teenagers in both States found the STC system to be useful, but not satisfying. Parents in both States found the STC system to be useful, but the Minnesota parents found it to be about half as satisfying, though satisfaction ratings were still positive.

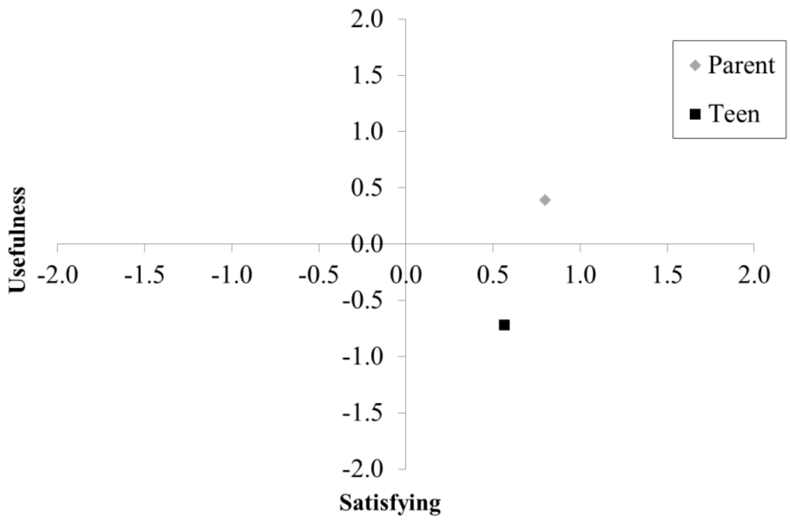


Figure 4-1. STC usefulness and satisfaction ratings for both teens and parents from Maryland.

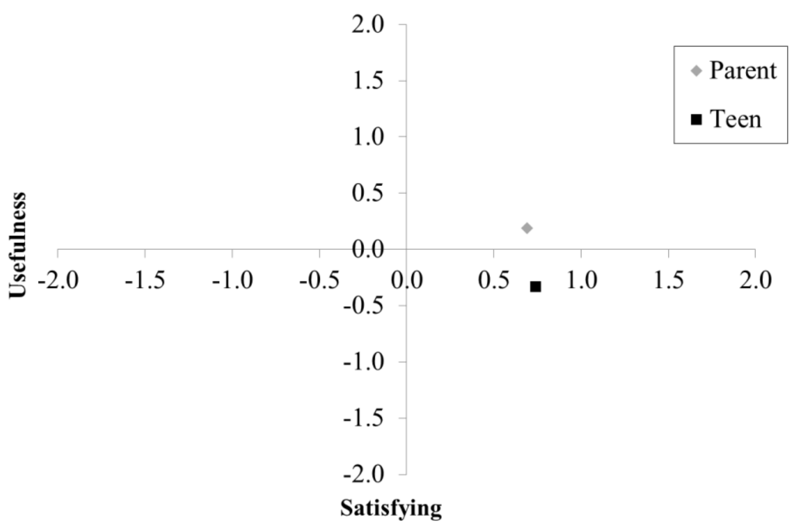


Figure 4-2. STC usefulness and satisfaction ratings for both teens and parents from Minnesota.

4.4.2 Trust discussions

Teens were presented with a series of questions that assessed their perceptions of trust in the STC relative to enhancing safety, familiarity with the system, trust, reliability, dependability, integrity, and confidence. Teens were asked to provide a score between 0 (strongly disagree) and 100 (strongly agree) based on the discussion presented to them. These scores were then averaged based on location (Minnesota, Maryland).

The discussions indicated that responses were influenced by location. Overall, Maryland teens had a greater number of positive responses regarding STC trust, reliability, dependability, and integrity than their Minnesota counterparts (see Table 4-8). The Minnesota teens reported slightly more confidence in STC enhanced safety compared to the neutral responses of the Maryland teens. Two of the trust responses did not vary due to location: system familiarity and confidence to drive without the STC. Teens were familiar with the STC regardless of location (Maryland reported 82.6% agreement compared to Minnesota's 88.2%), and were equally confident to drive without it (Maryland reported 90.0% average compared to Minnesota's 93.2%).

Table 4-8. Mean teen trust percentages by location (Minnesota and Maryland).

	The STC enhances safety	The STC can be trusted	The STC is reliable	The STC is dependable	The STC has integrity
Maryland	54.0%	69.7%	67.7%	69.7%	72.7%
Minnesota	60.0%	61.4%	57.6%	56.4%	63.9%

4.4.3 Teen and parent attitudes and safety

The majority of teens completely or somewhat agreed with the statement that the STC improved their safety (Maryland 66.7%, Minnesota 78.6%). When asked if the STC made them a better driver, less than half answered in the affirmative (Maryland 42.9% completely or somewhat agreed, Minnesota 35.7% completely or somewhat agreed). Minnesota teen drivers had a higher neutral response to the question (42.9%) when asked if the STC made them a better driver (see Table 4-9).

When the topic of STC unreliability was raised, only 13.3 percent of Maryland teenagers and 28.6 percent of Minnesota teenagers completely agreed or somewhat agreed that the system was unreliable. A majority of teenagers in both states (Maryland 86.6%, Minnesota 78.5%) completely or somewhat disagreed that specialized training and practice was necessary to drive with the STC.

In general, teenagers in both states were more likely to have a positive attitude when driving without the STC. While driving with the STC, 26.7 percent of Maryland teens and 35.7 percent of Minnesota teens reported slightly or very positive attitudes (see Table 4-10). When driving without the STC, a majority of teenagers in both states reported an increase in slightly or very positive attitudes (73.4% of Maryland teens and 64.3% of Minnesota teens).

When asked if the STC had changed the way they drove the majority of teens responded it probably or definitely changed their driving (Maryland 53.4%, Minnesota 71.4%, see Table 4-11). The majority of parents in both states also agreed (Maryland 73.4%, Minnesota 71.4%) that the STC influenced driving behaviors.

Table 4-9. Teen responses to interacting and using the STC by location as percentages of total responses per location.

I view the STC system as…		Completely Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Completely Agree
A system that improves safety	Maryland	--	13.3	20.0	40.0	26.7
	Minnesota	--	7.1	14.3	50.0	28.6
A system that makes me a better driver	Maryland	14.3	14.3	28.6	28.6	14.3
	Minnesota	7.1	14.3	42.9	28.6	7.1
Unreliable in its operations	Maryland	26.7	46.7	13.3	13.3	--
	Minnesota	14.3	35.7	21.4	28.6	--
Requires specialized training and practice	Maryland	53.3	33.3	6.7	--	6.7
	Minnesota	57.1	21.4	14.3	7.1	--

Table 4-10. Teen attitudes to driving with and without the STC system as percentages of total responses per location.

		Very Negative	Slightly Negative	Neutral	Slightly Positive	Very Positive
What is your attitude toward driving with STC?	Maryland	20	40	13.3	20	6.7
	Minnesota	--	21.4	42.9	28	7.6
What is your attitude toward driving without STC?	Maryland	--	--	26.7	46.7	26.7
	Minnesota	--	7.1	28.6	42.9	21.4

Table 4-11. Teen and parent/guardian comments regarding whether the STC changed teens driving as percentages of total responses per location.

Did STC change the way you/ your teen drive(s)?	Definitively did not change	Probably did not change	Not sure	Probably changed	Definitively changed
Maryland (Teen)	13.3	26.7	6.7	26.7	26.7
Maryland (Parent)	--	13.3	13.3	26.7	46.7
Minnesota (Teen)	7.1	7.1	14.3	50	21.4
Minnesota (Parent)	--	7.1	21.4	50	21.4

A majority of adults in both states found the system to be completely or somewhat satisfying Maryland 73.3%, Minnesota 78.6%, see Table 4-12). Their teenagers did not share the same level of satisfaction, with only 33.4 percent of Maryland teenagers and 42.8 percent of Minnesota teenagers finding the STC to be completely or somewhat satisfying. The reduced satisfaction level of the teens, specifically the Maryland teens, suggests there may be a greater impact of traffic density, trust, or privacy concerns from the teens. Unfortunately, specific causal factors could not be determined from this data.

Table 4-12. Teen and parent satisfaction with the STC system as percentages of total responses per location.

What was your overall satisfaction with the STC?	Not satisfied at all	Somewhat dissatisfied	Neutral	Somewhat satisfied	Completely satisfied
Maryland (Teen)	13.3	33.3	20	26.7	6.7
Maryland (Adult)	--	13.3	13.3	20.	53.3
Minnesota (Teen)	--	14.3	14.3	35.7	7.1
Minnesota (Adult)	7.1	14.3	--	64.3	14.3

4.4.4 Parent discussions

When the topic of recommending the STC to other parents was raised, participant responses differed based on location. Eighty percent of Maryland parents responded “yes” they would recommend the system to other parents, commenting that the system was a good reminder of important driving skills and promoted safety. Only 50 percent of Minnesota parents responded “yes” they would recommend it to other parents. Alternatively, 42.9 percent of Minnesota parents would “recommend the system, but with reservations,” citing system reliability and battery drainage problems. When the parents were asked whether they would recommend STC to other teens, the combined “yes” response from both groups was 89.7 percent. Parents also agreed unanimously (i.e., 100%) that the STC was not an invasion of privacy for their teens.

When parents were asked if they would pay for an STC option on a vehicle, 40.0 percent of Maryland parents and 35.7 percent of Minnesota indicated they would. There was greater interest among parents in both States to take a free system if it was part of the vehicle package (Maryland 46.7%, Minnesota 50.0%). Only two Maryland parents (13.3%) gave different answers (one was uncertain, the other was willing to rent the system), and two Minnesota parents (14.3%) indicated that they were not interested in the system at all.

A final discussion involved the potential price point of the STC if offered by vehicle manufacturers. The average price Maryland parents were willing to pay was $250 (SD=$148.32) whereas Minnesota parents were willing to pay an average of $318.75 (SD =$167.55).

4.4.5 Unstructured discussions

Both teens and parents of teens at each test location provided their general feedback relative to the STC (see Appendix G for specific responses). Responses were then organized based on specific subsystem information and general discussion themes for each subsystem. These discussions are summarized below:

4.4.5.1 Teen driver identification subsystem

The STC queried (via the display) upon vehicle ignition who was going to drive the vehicle if an RFID card was present. This feature was instituted to differentiate and potentially disengage the STC when an adult was present in the vehicle. Two parents noted that reliability issues were encountered that included not being able to make a choice (e.g., the screen not initiating) or the selection screen appearing while the vehicle was already in motion. Additional issues included not seeing the selection screen because it was not visible for a sufficient duration, forgetting the RFID card (at home), accidentally washing the RFID card with the laundry, not having enough RFID cards for all the drivers of the vehicle, and occasionally not seeing the selection system although the RFID card was present. These points suggest that the screen, upon vehicle ignition, needs to remain on longer to give participants ample time to make an appropriate selection. Several teens also mentioned that it was possible to steal the RFID card, although they did not do so. Future STC changes proposed by users included an RFID ignition key (rather than a card), using a passcode instead of an RFID card, and making the teenager carry the RFID card rather than the adult.

4.4.5.2 Speed monitoring and feedback subsystem

The predominant response to the SMFS was that the speed warning was effective and made teens more "aware of speed limits." Teens commented that they liked "knowing what the speed limit was." Teens did note some reliability issues with the SMFS, commenting that "the STC displayed the wrong speed limit from time to time," and "the STC would be slow in adjusting to the increased speed limit on highway acceleration ramps." These comments suggest that the speed database, though sufficient in most circumstances, may not provide accurate information for all roadway locations. Teens and parents also provided recommendations for future STC improvements (see Appendix G for specific comments) that included grading the visual and audio warnings as the speed threshold was increasingly exceeded, increasing the threshold for speeding, increasing flexibility of the system to include a time delay before the system gave feedback, and monitoring the radio volume such that the warnings could be discernible without interference from music.

4.4.5.3 Excessive maneuver and feedback subsystem

Teens responded positively to the presence of the EMFS, but most commented that it needed improvement. Responses included statements such as, "it helped me realize when I took turns too fast," "I was more careful going around corners," and "it changed my behavior going around turns." Potentially detrimental elements of the EMFS included annoyance issues that included "[the warning]…is too long" and "the warning was annoying." Teens commented that "the maneuver system was too sensitive," and on occasion, the alarm "seemed to be stuck on for several minutes." Suggestions for improvement included "shortening the tone to 5 seconds," and having "a graded system of mild and extreme maneuvers with difference warnings," and that "the system should warn the driver during turns rather than after the fact." Some teens also commented that they would like the EMFS to specify the nature of the maneuver that triggered the warning (e.g., aggressive driving, hard braking)

4.4.5.4 Seat belt detection and enhanced reminder subsystem

When discussing the SBDRS teens noted that the instructions were clear, they helped to establish a habit of seat belt checks, and helped to address peer pressure since the system, and not just the driver, required passenger seat belt use. Participants noted reliability as a large deficit of the SBDRS. Teens encountered "several false alarms" that included identifying non-existent people (e.g., "passenger side seat belt alarm went off when nobody was sitting there" or "backpack was on the seat"). Parents and teens suggested greater sensitivity for identifying actual passengers that in turn would increase trust and reliability of the system. One teen also suggested that the SBDRS withhold warnings until the car was shifted out of the park gear.

4.4.5.5 Driving context subsystem

Driver awareness of the effects of the DCS was lower than for the other STC subsystems. Approximately half of the teens noticed that the STC was more sensitive at night, or when carrying additional passengers. Perhaps due to the subtle nature of the DCS no teens encountered reliability or distraction issues relative to this subsystem and, as a result, offered few suggestions for improvements to future system iterations. Suggested improvements included weather-specific detection (snow/rain), external illumination, and increased precision in the detection of day/night limitations.

5 Discussion and General Recommendations

The primary purpose of the full STC evaluation was to identify teen driver behavioral changes in response to the entire STC system. Secondary goals of the evaluation were to identify behavioral changes in response to STC use over extended periods of time, to determine if behavioral changes corresponding to STC use continue (i.e., carry over) after the system is deactivated, and to understand how teens and their parents subjectively view the STC in terms of trust, satisfaction, and usefulness. To accomplish these goals a ten-week study was initiated with a two-week baseline period prior to STC activation to identify driving behaviors in the absence of feedback, then with a six-week treatment period to identify the extent of behavioral changes due to STC use, and then a two-week transfer period in which the STC was deactivated to examine carry-over effects. Overall, results from the evaluation suggest that the STC feedback and vehicle adaptations influenced teen driver behaviors in several positive ways over time and that both teens and parents generally rated the STC positively. The following sections provide a discussion relative to each STC subsystem in addition to recommendations for implementation.

5.1 Teen driver identification subsystem

The primary purpose of the STC is to provide feedback and vehicle adaptations to teens when risky driving behaviors are observed. Ideally, teens would respond by reducing the rate of these behaviors and thus reducing their overall level of risk. To take full advantage of the feedback and adaptation it is important that teens be exposed to the STC whenever they drive (thus preventing circumvention of the STC benefits) that requires the STC to be active whenever the vehicle is started. However, there must be a mechanism within the STC to disengage the STC for various reasons including allowing parents to instruct their teens without the support of the STC and allowing parents or sibling who do not need support to drive the vehicle without STC assistance. To address this issue a TDIS was included in the STC that prompted drivers to select either teen or parent (no support) mode when a “smart key” was present (signaling the presence of a parent). The smart keys used radio frequency identification technology to communicate with the STC. The STC subsequently provided the modal choice to the driver and, based on the driver response, either activated or did not activate the STC features. Currently RFID technology is in use by vehicle manufacturers for automatically detecting and adjusting seat and mirror positions based on individual driver profiles. The same type of technology can be implemented by manufacturers for the implementation of a TDIS within the STC.

Recommendations: Based on the needs identified above it is recommended that an OEM-based STC include teen driver identification functionality. Based on the results of the current work and feedback from parents the TDIS should retain the ability to select teen and parent (non-teen) modes. However, feedback from participants suggests that the duration of mode selection be extended and that the reliability of the TDIS presentation upon vehicle start-up be improved. Further, it is recommended that there should be more than one method to select STC mode to accommodate situations such as lost RFID cards. This could be easily accomplished by incorporating the RFID technology into a key that also starts the vehicle, a technology that is already in use by vehicle manufacturers.

5.2 Speed monitoring and feedback subsystem

A primary risk factor for teen drivers is speeding. To address this risk factor the STC included a SMFS that compared a teen driver's current speed against the posted speed limit and, depending on the degree of speeding over the limit and the presence of additional risk factors (e.g., passenger presence), provided feedback and vehicle adaptations.

Figure 5-1 presents a graph of the percentage of miles in which teens exceeded the posted speed limit by a particular amount for each treatment stage. The figure shows the distribution of speeds across four speeding categories (0-5 mph; >5-10 mph; > 10-15 mph; 15+ mph) for each of the five phases of the experiment. Panel A of Figure 5-1 shows data for the case where the driver was alone in the vehicle. Panel B shows the case where there were one or more passengers present. Note that the rates of speeding are roughly double for the case where the driver is alone, relative to with passengers. This presumably is due to the lower threshold for the speed warning when passengers are present, but could also be related to passenger presence itself or to trip characteristics under which passenger trips occur. For the driver alone case, Panel A indicates that there is a lower incidence of speeding in the 5 to 15 mph exceedance range during the treatment conditions (solid lines) compared to the baseline and transfer conditions (broken lines). When passengers are present, and the speeding thresholds are already quite a bit lower, only the distribution for the "immediate" treatment stage (i.e., the stage following baseline) appears substantially reduced. These distributions suggest a general reduction in speeding during the feedback periods. Analyses of variance (Table 4-3) show a significant main effect of stage for the >5 to 10 mph exceedance for driver-alone, and a significant main effect of stage for the >10 to 15 mph exceedance for both driver-alone and driver-with-passenger(s). However, few individual paired comparisons reached statistical significance. Results of the current work indicated a statistically significant reduction in miles speeding (4.6%) between the baseline and treatment stages for the >5-10 mph above the speed limit dependent variable. Although this difference is not statistically large, if an STC is widely deployed this small difference may have a large impact on overall speeding behaviors within this speed zone. Within the same dataset the amount of speeding miles for the 10-15 mph above the speed limit dependent variable increased significantly (2%) after the STC was removed from use.

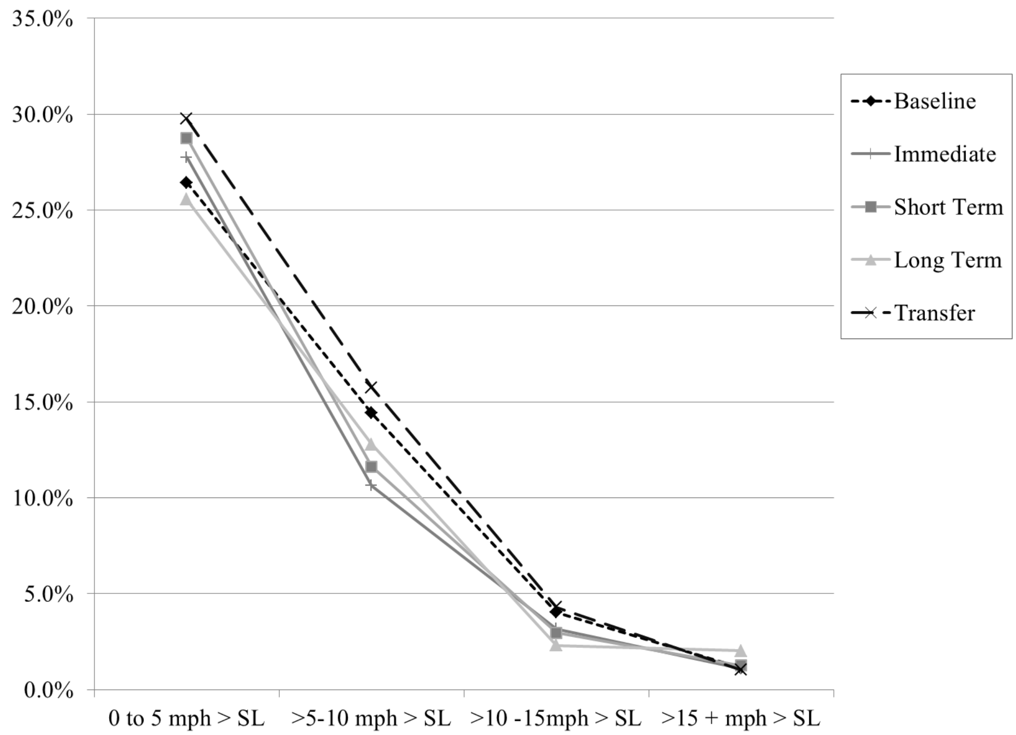
The results of these analyses and anecdotal comments by teen drivers support several interesting findings. As indicated in Figure 5-1 there was a gradual increase in the average number of miles speeding for the 0-5 mph over the speed limit dependent variable from the baseline to the immediate and then the short-term acquisition stage. Anecdotal comments provided by teen drivers indicated that the tone they received when exceeding the speed limit by a small margin (e.g., 2 mph in most cases) was a useful reminder indicating that they were near the posted speed limit. It is posited that teens used this reminder as a "marker" for appropriate vehicle speed. The result was an increase in the percentage of speeding miles traveled around this marker (which falls within the 0-5 mph over the limit speed zone). When the STC was deactivated during the transfer stage, teens increased the percentage of miles traveled in this zone. This finding lends some support to the notion of negative behavioral adaptation upon system removal where teens reverted back to higher speeding trends when the STC was deactivated.

Alternatively, the results can be interpreted as supporting the notion that teens may have developed a strong association between the marker and their speed during system use and that upon system removal drivers continued to constrain their speed within this zone. This interpretation actually suggests positive behavior adaptation in response to system removal. A second finding is the U-shaped pattern observed in the 5-10 and the 10-15 mph speed zone dependent variables across treatment stages that indicate an initial reduction in percentage of miles speeding in each of these zones during STC use and a return to approximately original levels when the STC was removed from use. These findings provide initial positive support for STC use. However, it is important to view the two interpretations from these findings with caution because portions of the interpretations are based on differences in mean scores that did not achieve statistical significance.

Differences in speeding exceedance rates occurred between the two testing locations as indicated by a significant interaction between stage and location for the 10-15 mph over the limit dependent variable. Figure 5-2 shows a plot of the Maryland and Minnesota teen speeding behaviors for each stage of the evaluation. Although follow-up tests were not significant, a trend may exist in that Minnesota teens reduced the percentage of miles driven in this speed zone sooner than their Maryland counterparts and that by the time the Maryland teens began reducing the percentage of miles driven in this speed zone the Minnesota teens were exhibiting the opposite behavior. When the STC was then deactivated the percentage of miles driven in this speed zone increased for teens at both locations, but the increase was markedly higher and above initial baseline stage levels for the Minnesota teens. Why these results occurred between locations with respect to this speed zone is not well understood.

During the unstructured discussions about the SMFS the majority of teens considered it to be effective and said it made them more aware of the speed limits (that they could see on the display and hear via the tonal warning). Parents and teens also suggested a few improvements for the SMFS that included grading the speed feedback by increasing the volume at higher speeds and altering the volume of the warnings to compensate for radio volume. This latter suggestion is insightful as vehicle manufacturers could easily alter warning volume or, by virtue of vehicle adaptation, lower the radio volume when a warning occurs.

A. Driver Alone



B. With Passenger(s)

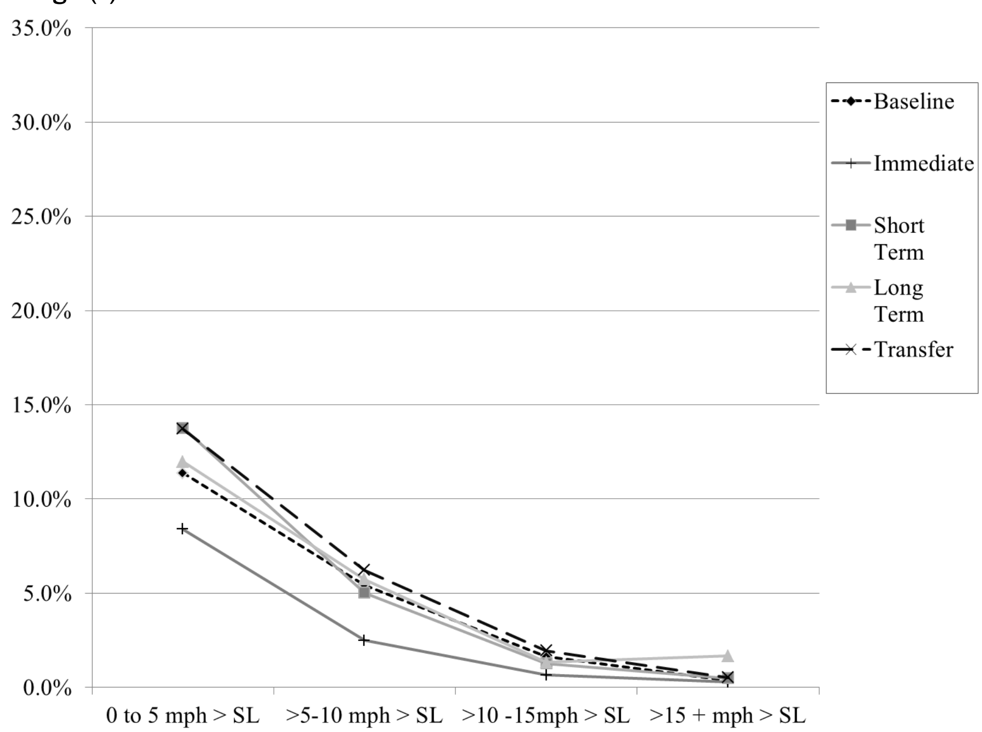


Figure 5-1. Mean percentage of miles with speeding exceedance (four levels of exceedance) for combined daytime and nighttime driving. Panel A: Driver alone. Panel B: Driver with passenger(s).

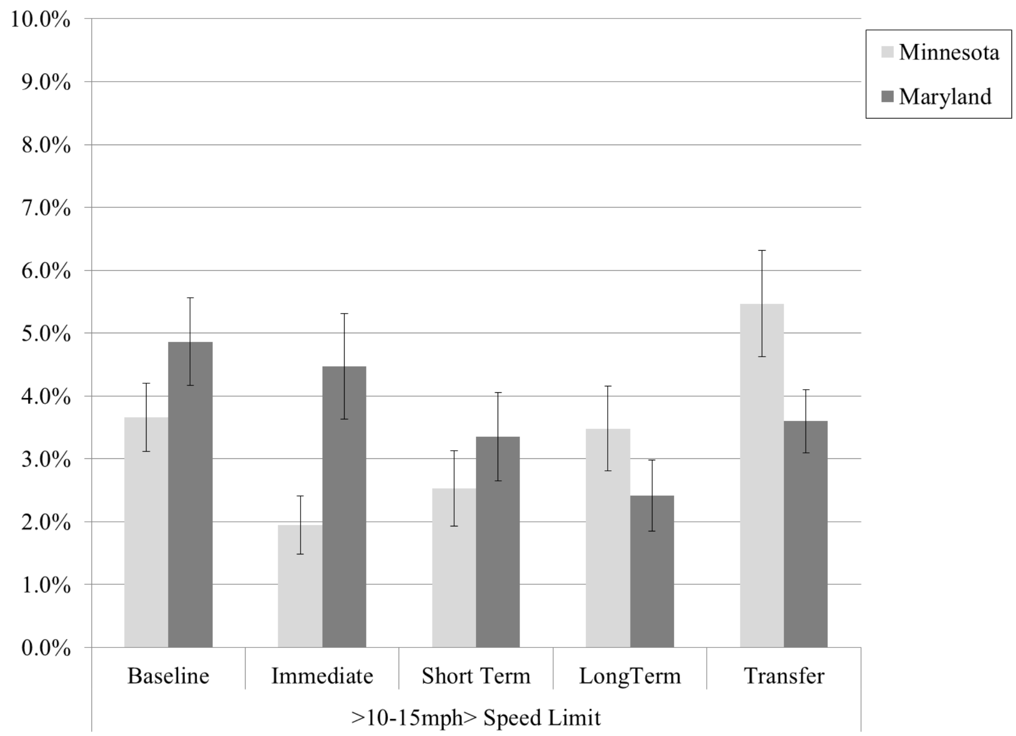


Figure 5-2. Mean percentage of speeding exceedance rates by stage and location for driver combined day and nighttime data. Error bars represent ± 1 standard error of the mean.

A few teens from both locations commented that the incorrect speed limit would be displayed for certain sections of roadway and that the system was at times slow in updating the speed information when merging onto a highway. The speed database used to identify and compare speeds was extensive, however there were areas with limited or no speed limit database information. Furthermore, if a speed limit on a particular roadway had been changed recently but not updated within the database participants would encounter situations where the speed limit information was incorrect. These incorrect speed events were infrequent and equally as likely to occur to any participant, thus the potential confound of incorrect speed information was equally spread across participants. These limitations indicate potential gaps in the technology where continual updates to the speed database are required to maintain the effectiveness of the SMFS.

Recommendations: The SMFS identified the location of the vehicle (via GPS information) and the associated current regulatory speed limits (i.e. posted speed limit) and compared this information against the teen's actual speed to determine the degree to which a teen was speeding. It is suggested this subsystem be employed in future STC systems because the visual and auditory information were positively received by teens and allowed them to "know" what speed they were traveling. As a result, teen speeding behaviors were positively influenced in some situations. However, we recommend additional research that examines driver attitudes and potential behavioral changes in response to graded feedback (e.g., infotainment lockout) by the SMFS as a result of speeding. We also recommend the conduct of additional research examining potential negative behavioral adaptations by teens due to the data within the 0-5, 5-10, and 10-15 mph over the speed limit dependent variables that indicated an increase in miles speeding in those speed zones when the STC was removed from use. In particular, additional work is needed to statistically confirm the trends that were observed in the first and second speed zones.

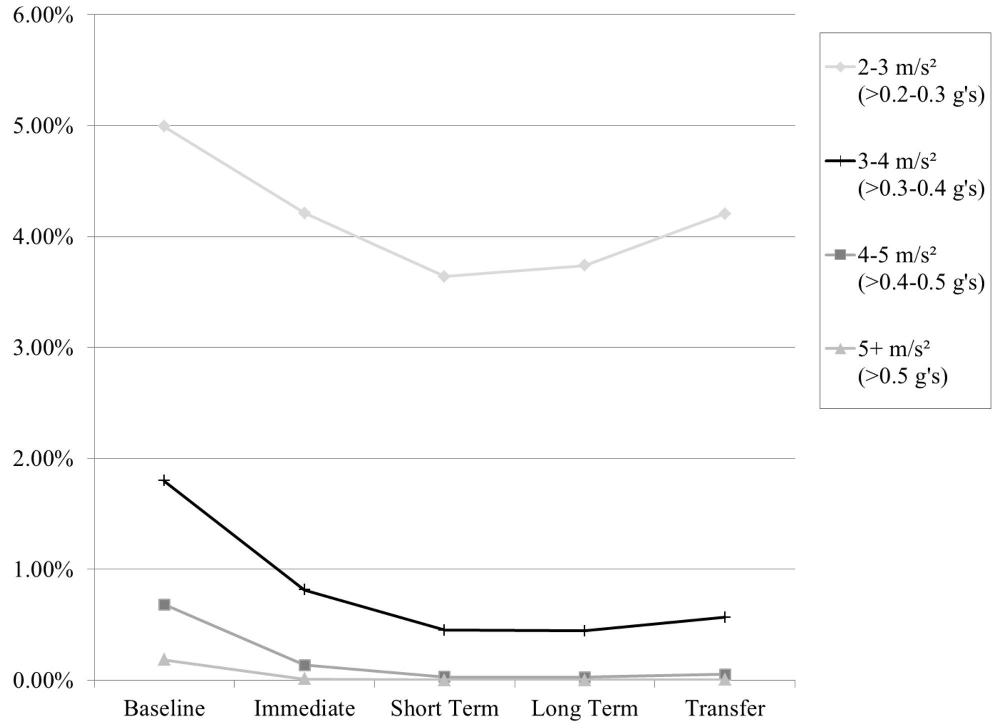
5.3 Excessive maneuver and feedback subsystem

Figure 5-3 shows the percentage of miles driven that included a maximum lateral or longitudinal acceleration of a given degree, during each of the five phases of the experiment. Panel A shows the case where the driver is alone in the vehicle. Panel B shows the case where there were one or more passengers present. Note that the rates of these excessive maneuvers were generally more than doubled when the driver was alone. This presumably is due to the lower threshold for a warning when passengers are present, but could also be related to passenger presence itself or to trip characteristics under which passenger trips occur. For the driver alone case, Panel A shows a drop in the frequency of excessive maneuvers from the baseline to the treatment conditions; however, the main effect of stage was not statistically significant (Table 5-3). Panel B also shows a drop from the baseline to treatment conditions. The main effect with passengers present was statistically significant only for 4-5 m/s^2 case.

Analyses on the EMFS data indicated a main effect for time of day for the 2-3 m/s^2 longitudinal negative (e.g., slowing) dependent variable. Teen drivers reduced excessive maneuvers per mile at nighttime compared to daytime. The results may also indicate a changing influence of traffic patterns between the day and nighttime conditions. Additional braking, due to increased traffic in daytime conditions could be influencing the results. As seen in Figure 5-4, there was also a general trend observed for daytime excessive maneuvers to decrease over time during STC use and that it remained lower than the baseline stage after STC use was discontinued for both nighttime and daytime. These results support the contention that the EMFS does influence teen driver behavior by reducing the number of excessive braking instances. The adaptive features of the subsystem are also effective for excessive maneuvers because thresholds for this system became more restrictive at night.

A significant main effect for stage was found for the 4-5m/s^2 lateral negative maneuvers (i.e., right turn) dependent variable for the passenger present dataset (see Figure 5-5). Post hoc analyses indicated a significant reduction in these lateral maneuvers between the baseline and immediate stages for this maneuver. Interestingly, there was a marked trend for the rate of lateral maneuvers within the 3-4, and 4-5 m/s^2 dependent variables to decrease when teens were first exposed to the STC and then remain lower than baseline levels throughout the remainder of the study. However, the rate of lateral negative maneuvers for the 2-3 m/s^2 dependent variable began to increase throughout STC use but declined further and carried this lower effect into the transfer stage. Collectively, the significant differences and the trends suggest a positive impact on teen driving behaviors for lateral negative maneuvers that are experienced by teens on a more regular basis and little effect for extreme maneuvers that are rarely experience (and thus situations in which feedback is rarely provided).

A. Driver Alone



B. With Passenger(s)

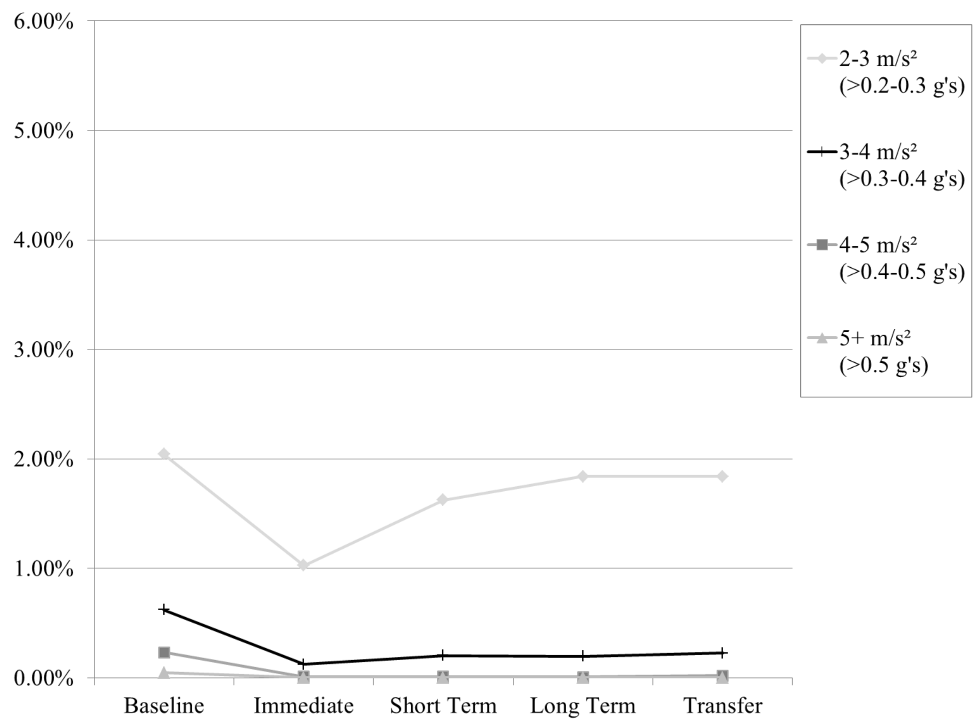


Figure 5-3. Mean percentage of miles with excessive maneuvers (lateral and longitudinal) for combined daytime and nighttime driving. Panel A: Driver alone. Panel B: Driver with passenger(s).

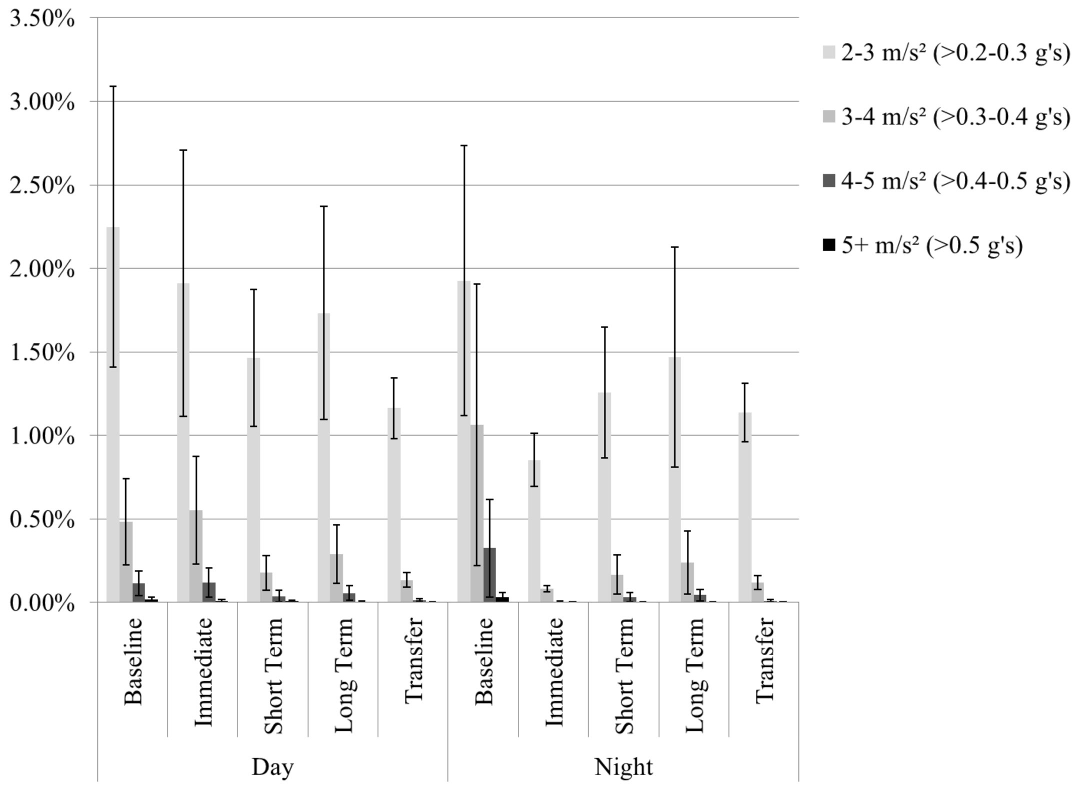


Figure 5-4. Mean proportion of miles with excessive maneuvers for drivers and negative longitudinal (i.e., slowing) behavior based on stage for day and night driving. Error bars represent ± 1 standard error of the mean.

Overall, teens responded positively to the feedback provided by the EMFS and commented that it helped them avoid taking corners too fast and made them aware of vehicle maneuvers. However, teens also commented that the warning was too long and the single tone was annoying. Some teens found the subsystem too sensitive because it issued feedback in situations they thought were "normal." Teens who encountered these situations suggested that the sensitivity of the system be monitored such that feedback could be provided in a graded manner. Teens would receive different levels of warnings between "mild" and "extreme" maneuvers.

Recommendations: Overall, the EMFS resulted in several positive behavioral effects and teens and parents found this subsystem useful. We suggest the use of this subsystem in future iterations of the STC, but recommend some modifications to enhance utility/acceptance. These changes include reducing the duration of the auditory warning to a maximum of five seconds and changing the tone of the auditory warning; both changes should result in improved driver acceptance of this subsystem.

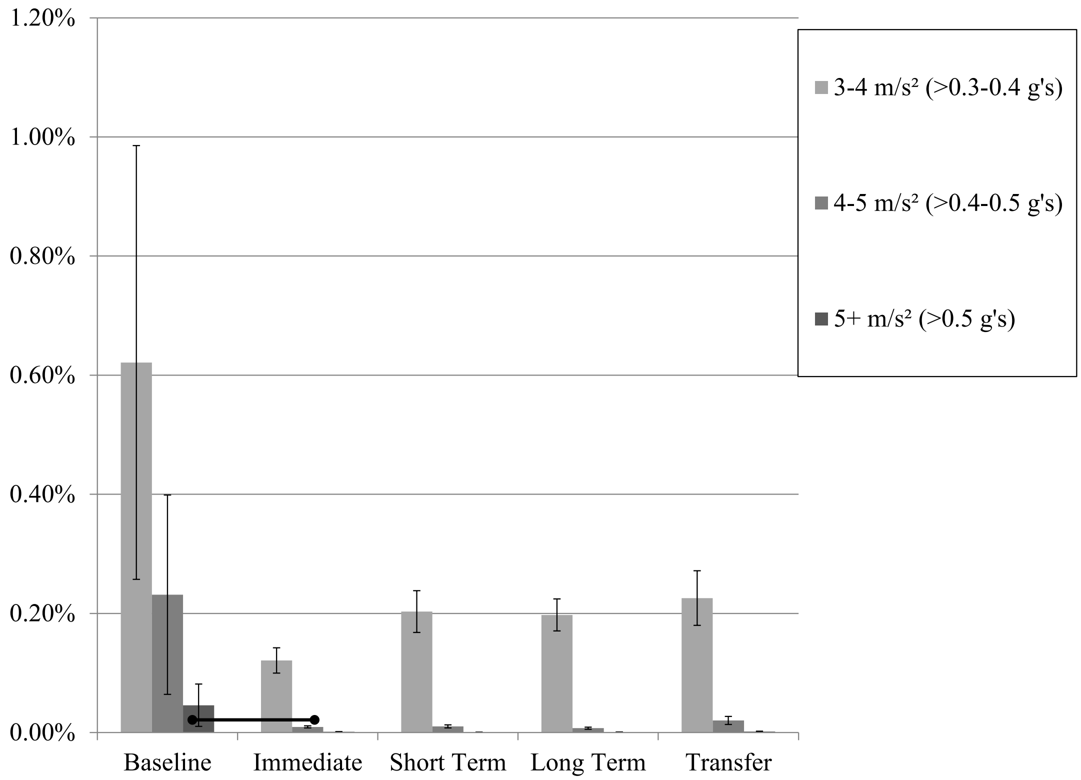


Figure 5-5. Mean percent of miles with excessive maneuvers for the lateral negative maneuver for drivers and passengers. Error bars represent ± 1 standard error of the mean.

Additional modifications may include utilizing only the longitudinal feedback in light of participant comments that indicated some reduced understanding of lateral maneuver feedback (i.e., challenges associating lateral feedback with a lateral maneuver). If lateral feedback is retained it is recommended that the meanings of the warnings be enhanced (e.g., directional icons). This subsystem can also be linked to other systems within the vehicle (e.g., electronic stability control and/or driving context subsystem) to notify drivers of situational effects on vehicle maneuvers.

5.4 Seat belt detection and enhanced reminder subsystem

Figure 5-6 shows the percentage of miles during which there was nonuse of the seat belt during each phase of the experiment. The data are shown separately for each seat position. For all four seat positions, the failure to use a seat belt was lowest during some portion of the treatment period; nonuse was generally higher during the baseline and transfer phases. Since seat belt usage was quite high for the front seat positions (about 95% during baseline), the improvement in seat belt usage during the treatment phases was not large in absolute terms, but remained consistent. Given that the majority of teen vehicle occupant fatalities were unbelted, even a relatively small increase in the percentage of belted occupants has meaningful safety implications. However, as indicated in Table 4-3, the main effect of treatment stage was statistically significant only for the right side rear seat position. Although this relatively small-scale evaluation did not have the power to discriminate small shifts in the rate of seat belt use, this should not be taken to imply that there is no benefit to the system, given the potential safety benefits of even small shifts in usage rates.

Analyses conducted on the SBDRS data indicated a significant main effect for time of day for the right side rear passenger position. The data indicated a reduction in seat belt compliance of 15.7 percent for the right side rear passengers at night when compared to daytime conditions. The reduction in compliance for this specific position between day and night is not well understood and may reflect the increased risk taking of rear seat passengers at night when driving with fellow teens.

The follow-up paired comparisons for the main effect of stage for the right side rear passenger indicated an increase of 16.5 percent in the compliance rate between the immediate and short-term treatment stages (see Figure 5-6). These results are particularly promising as it shows rear passengers are influenced by the feedback and that teens may have been enforcing seat belt compliance with the assistance of the system. As an example, teens noted that the STC feedback helped drivers identify the lack of seat belt compliance by passengers that the STC gave drivers an excuse to enforce compliance (e.g., the system is telling you to buckle up). It is important to note that caution should be taken when interpreting the data from the rear passenger area. The amount of rear passenger data collected in this study was quite limited compared to front seat passengers. The rear passenger data were less consistent and less abundant than the data collected from the driver or the front passenger. While the results are encouraging, future research should identify and further monitor rear seat belt compliance.

The observations were supported by anecdotal comments from teens who responded that the SBDRS provided a clear message about seat belt use and also helped them establish a habit of seat belt checks for all seating positions.

A significant issue relative to this subsystem was reliability. A few participants noted that seat belt buckle magnets had become dislodged that in turn would give off warnings even though the person was buckled. In a few instances false alarms occurred where the system issued a warning for one of the seating positions where nobody was seated. Both teens and parents suggested a greater need to increase the sensitivity for identifying actual passengers so that trust in the system would be maintained.

Recommendations: The SBDRS reminds and motivates teen drivers and occupants to use their seat belts. It is recommended the SBDRS be retained in future STC configurations to maintain high seat belt compliance rates for drivers and front passengers and to promote seat belt compliance among rear passengers. It is recommended that the multistage reminder system be retained. In an effort to encourage seat belt compliance, the system activates in two specific stages. The first stage gives the teen a mild reminder where the teen is prompted to buckle their seat belt and the second stage only occurs if there is continued non-compliance. It is also recommended that the subsystem be coupled with the passenger presence subsystem so that redundant seating information can be exchanged between the subsystems and thus increase the accuracy and reliability of the SBDRS.

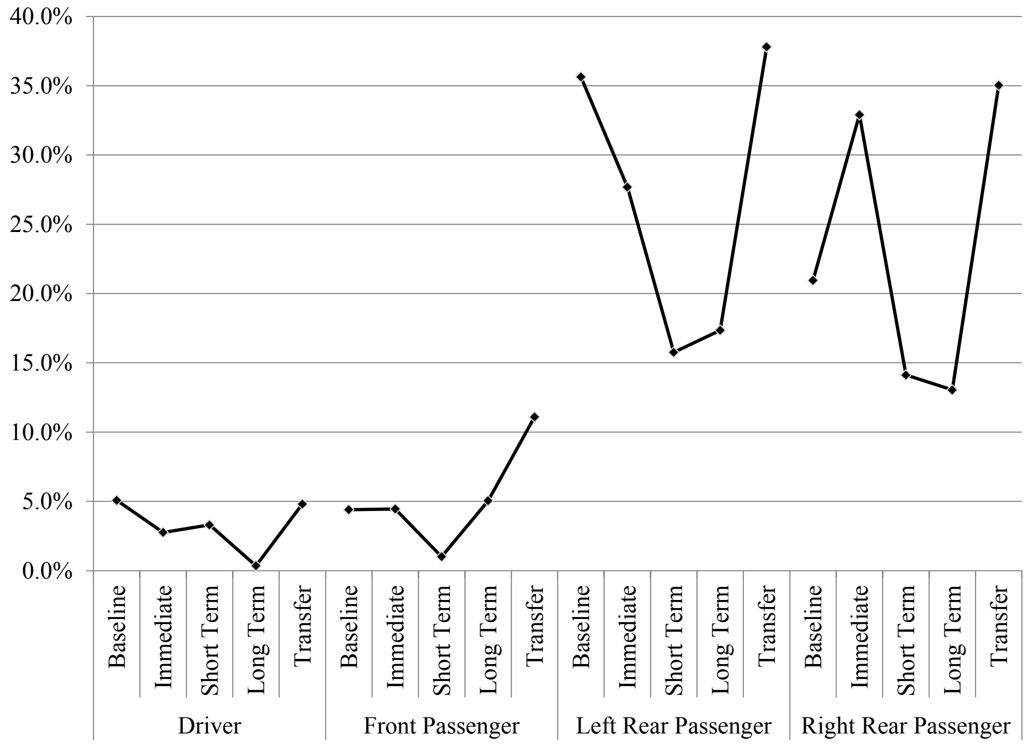


Figure 5-6. Mean percentage of miles with seat belt nonuse for combined daytime and nighttime driving, by seat position.

5.5 Passenger presence subsystem

There were no differences found for the PPS. This indicates that the presence of the subsystem did not influence the likelihood of passenger presence. The PPS did directly influence the speed management and excessive maneuver subsystem thresholds by lowering them when three passengers were present in the vehicle. In a few cases, parents and teens noted that the detection of passengers needs further refinement as heavy objects (e.g., a heavy backpack) placed on the seat would give a false indication of an unbelted occupant. There is a general need to increase the reliability of the detection system so that trust and satisfaction can be maintained for participants.

Recommendations: The PPS is a support function for the seat belt detection and driving behavior feedback. It is recommended that this subsystem be retained as part of the STC due to the fact that the PPS complements allied STC subsystems (e.g., seat belt detection and excessive maneuver). The central recommendation is to improve detection accuracy such that false alarms are reduced. This facilitates the functionality of allied subsystems and would improve driver acceptance.

5.6 Driving context subsystem

The results from the ten-week evaluation indicated a general benefit of DCS for both daytime and nighttime conditions. Significant differences were found between daytime and nighttime driving for both the excessive maneuver and speed management subsystems such that greater improvements were found at night. This suggests that the lowered feedback threshold at night led to safer driving during this risky time of day. Participants' suggestions for improvements or additions to the subsystem included weather detection (e.g., snow/rain) and increased precision in daytime and nighttime detection (e.g., dawn and dusk).

Recommendations: The DCS provided time of day information to other subsystems based on a GPS time stamp. The information from this subsystem can be easily employed by vehicle manufacturers and has proven to be beneficial to allied subsystems. In light of this it is recommended that the DCS be retained in future STC iterations. Due to the ease with which the data can be obtained and the potential benefit of a broader DCS, we also recommend that vehicle manufacturers include measures of precipitation that can be identified by windshield wiper activation and roadway icing that may be inferred by temperature, humidity, or precipitation data. In both of these cases the thresholds for the speed management subsystem and the excessive maneuver subsystems would be decreased in an effort to address the increased risk due to these conditions.

5.7 STC subsystem adaptations

The adaptive features of the STC provided a novel way to influence feedback for several subsystems based on the presence of risk factors detected by allied subsystems. As an example, if a teen was driving at night the feedback thresholds for the speeding management and excessive maneuver subsystems were reduced. Similarly, if a teen was speeding, the excessive maneuver subsystem feedback threshold was reduced. In this way the STC could address/control at least one risk factor if another was detected. Results of the current work suggest that the adaptive nature of the STC facilitated changes in performance that reduced overall risk. This was most evident in several significant findings in which driving behaviors at night were influenced positively. Based on these results and the notion that adaptive features can be easily included in vehicles it is recommended that these features be retained in future iterations of the STC.

5.8 Cell phone use detection and mitigation subsystem

The goal of the CDMS was to provide feedback to teen drivers and institute vehicle adaptations to allied subsystems (e.g., reducing feedback thresholds for speeding) if cell phone use was detected. This was intended to be a central feature of the STC to manage a known risk for teen drivers due to cell phone use, but preliminary pilot testing revealed that the available cell phone use detection technology proved to be unusable for the full STC evaluation due to poor reliability and accuracy. Furthermore, adequate technology is still unavailable commercially due to continued technological limitations. This is unfortunate as cell phone use (and texting) continues to be a significant safety concern for all drivers, but especially teen drivers.

The significant risk associated with cell phone use would support the contention that the inclusion of *any* detection technology might be warranted. However, based on teen and parent feedback within the pilot work conducted as part of this project, a poorly performing detection subsystem would be perceived as a significant annoyance and would negatively impact perceptions of the other subsystems. The result would be that teens and parents view the entire STC negatively and would prefer not to use the system. This would deny teens the benefits of the other useful subsystems. In light of this we recommend that a CDMS not be included in STC designs at this time. Instead, substantial effort should be dedicated to improving the accuracy and reliability of this technology.

5.9 Recommendations and limitations

Several limitations may have influenced the results of the current work. These limitations form the basis of several recommendations for future work that would further elucidate the effects of STC technology on teen driving behavior.

- STC exposure. Research has indicated that crash risk is significantly elevated within the first six months of licensure. Due to insurance considerations and the need for a driver to possess rudimentary driving skills, the current work involved teens who had a minimum of six months of driving experience. It is possible that the effects of the STC observed in the current work may be different (e.g., accentuated) for teens within the first six months of licensure. Certainly, if the STC can guide teens towards positive driving behaviors, results may show a greater positive effect during STC exposure and potentially stronger carry-over effects after the STC is deactivated. It would be beneficial to conduct a study similar to that presented here but with teen drivers within the first six months of licensure. Furthermore, the positive results obtained for the STC from the present research effort would likely carry-over to older teen and adult novice drivers. The degree of benefit for these additional groups is not known and would require additional research.
- Duration of treatment exposure. Several of the dependent variables exhibited significant findings and trends throughout the data acquisition stages that were indicative of both positive and negative behavioral adaptation through continued STC exposure. However, the duration of STC exposure was limited to six weeks due to project timing and financial considerations. It would be informative to extend the period of STC exposure to document more fully the longer-term effects of STC use.
- Duration of transfer exposure. Similar to the duration of treatment exposure an extended period of transfer exposure would provide additional information regarding the effects of STC deactivation on driving behaviors. In particular, does the STC facilitate improved driving behaviors beyond the two-week no-STC timeframe employed in the current work? At what point might any improvements observed in the transfer stage asymptote and how long before the effects diminish?
- Participant sample size. The sample size of the STC field evaluation was limited, with 15 teen drivers at each of two locations (N=30). While preliminary power analyses indicated this sample size would be sufficient, a study of this magnitude and potential real-world impact on teen driver safety would benefit from an increased number of participants to determine if the positive trends in the datasets would be statistically significant. A larger study would more reliably determine what behaviors are likely to be affected by the STC and could more precisely quantify the degree of behavioral change. One of the findings from the current work is that several of the follow up statistical interactions, main effects, and paired comparisons were not significant despite marked differences between the means (which were often also paired with low standard error). Many of these did not reach significance due to the extent of the Bonferonni correction employed to control for the increased number of comparisons. Increasing the participant sample size might allow these trends to reach significance thus allowing researchers to have greater confidence in the direction of the data trends.
- Control group. The addition of a control group in future research is recommended. The control group would be a between subjects factor that would monitor drivers in parallel with the treatment group. A control group could be further matched based on gender and driver

experience. The control group would then allow for a comparison between actual treatment effects compared to those individuals without the STC.

- Sophistication and performance of the implementation. In order to implement STC capabilities in participants' personal vehicles for the field evaluation, it was necessary to devise portable, inexpensive "aftermarket" instrumentation that would not damage, mar, or otherwise interfere with the vehicle. Actual OEM implementations would be expected to have much better integration, accuracy, and reliability. Limitations to the tested system in terms of reliability, nuisance alarms, intrusiveness, and esthetics may have influenced system effectiveness or user attitudes.
- This project had the objective of demonstrating a prototype STC. The features and functions incorporated into the system were based on consideration of the literature on teenage drivers and their associated crash characteristics. In implementing these functions, design features and parameters, such as thresholds, feedback display timing and characteristics, and adaptive algorithms, the research team had to make selections based on existing literature, expert judgment, or informal piloting. Implementation was also based on cost considerations for a non-intrusive experimental platform introduced into a participant's vehicle. The project did not have the much more extensive resources that would be required to empirically determine the optimal design choices for every function. Rather, best-judgment choices were used to provide a proof-of-concept. At this point, it may now be useful to conduct further study to optimize system design, which may enhance the findings and trends observed in the present study.
- While the results of the current work did indicate some positive benefits of STC use, we encourage readers to interpret the results with caution due to the limitations associated with the current work. Further large-scale research is required that examines increased exposure to an STC and comparisons to a control group. Furthermore, expanding the participant pool to other states will likely encourage exposure to varied driving behaviors of teens around the country that may in turn reflect different seat belt use rates, speeding behaviors and the overall utility of the STC.
- Finally, as with many research efforts, there is a potential confound with respect to participant engagement in the study. In particular, participants were aware that data collection equipment was installed in their vehicle and they may have biased their behaviors simply due to the presence of the equipment regardless of whether or not it provided feedback. As with most behavioral studies we assume this confound was omnipresent and likely influenced all drivers similarly in the current work. It was beyond the scope of the current work to examine the extent of the confound's influence.
- Previous research (Dingus et al., 2006) of longer-term monitoring of driver behavior indicates that drivers seem to forget they are being monitored early in the study period. Relative to the current work an examination of driver behavior between the treatment groups indicated that those drivers in the baseline condition did not significantly modify their behavior either at the beginning of the study period or at the end, suggesting that the presence of the system alone (i.e., not providing feedback during the baseline periods) had little effect on driver behavior.

5.10 Lessons learned for Subsequent Research

The project provided unique challenges and findings through the course of the research effort. These findings provided insight into teen driver behavior, STC interaction, and hardware capabilities with the system. Future research can benefit from these insights in an effort to maximize positive outcomes and preemptively mitigate potential issues. These experiences include:

- Teens are receptive to in-vehicle feedback and vehicle adaptations that adapted to their driving. The general discussions with teens suggested that the STC did not invade their privacy and gave them additional information to enhance their driving behavior. Furthermore, the hardware for the STC was readily accessible and only one system was subject to tampering. Lastly, teens were responsive in offering future improvements for future iterations of an STC in an effort to improve overall effectiveness.
- A number of interactions occurred between the Maryland and Minnesota teen data. While the choice to use two locations was intentional and provided a snapshot of teen driving behavior and reactions to the STC, there are a number of lessons to be learned. How and why location played a role is not well understood due to a number of contributing factors. It is difficult to ascribe a reason for these interactions and likely included differences based on driving environment (urban, suburban, and rural), state police enforcement practices, DMV requirements, and teen driving programs, to name a few. Future comparisons between states (and countries) will need to identify these subtle contributing factors to improve methodological rigor.
- Stakeholder input and review was valuable throughout the project effort. A review and demonstration effort was presented part way through the current research project and provided valuable feedback for the STC from an external perspective. A final review and presentation with various stakeholders would have been beneficial for future research efforts.
- Hardware and software failures resulting in software data loss are a potential part of any research project. The current research employed face-to-face contact in the field and phoning participants as part of the quality assurance effort. If an issue was identified the research team mobilized quickly to resolve the issue and continue data collection. However, some participants were less responsive than others and required additional effort to identify any potential issues. The rapid response and correction of potential system issues was due in part to a small sample size and flexible participant schedules. Future research with larger sample sizes and extended data collection periods may not have this immediate flexibility. The research team suggests developing a quality assurance plan in-depth prior to deployment of similar systems.

5.11 Specifications

A set of formal operational specifications was developed based on research and recommendations identified as part of STC research effort. The Final Specification report, shown in Appendix J, provides operational specifications for each of the following subsystems.

- Teen driver identification system
- Passenger presence and detection system
- Seat belt detection system
- Speed monitoring and feedback system
- Excessive maneuver and feedback system
- Driving context system
- Cell phone detection system

In addition, the document provides recommendations for the adaptive features of the system.

5.12 Outline of a parent/teen driving program

A final consideration in this project was how one might devise consumer information programs that provide parents and teens with relevant information on the causes of crashes and what role technology can play in mitigating those crashes. The task was not to develop any such program but rather to outline the elements of such programs. This includes behaviors that contribute to teen crashes, how technology can help prevent those crashes, and how the technology may achieve widespread deployment. The "technology" referred to is a STC-like system, which is an original equipment feature (whether standard or optional) of a passenger vehicle. This is not a treatment of after-market products, driver training services, or other programs that are based on reporting or coaching.

It should be understood that this consumer information program is not intended to be associated with a particular product or manufacturer. The material should deal with the benefits and concerns of a generic STC system. Ideally this information would be provided as NHTSA-developed material. It is assumed that the information will reflect state-of-the-art in-vehicle technology at the time the information is produced, and not be limited to STC capabilities as reflected in the current project. For example, there are emerging capabilities for sensing such things as driver visual inattention or drowsiness. To the extent such capabilities are present in vehicles, their use can be tailored so that they are optimized for teen drivers as part of the STC system.

The outline below indicates recommendations for a consumer information program under four primary topics:

- What sort of informational materials should be developed?
- How may the information be disseminated to parents and/or teens?
- What incentives can be included to motivate interest?
- What should the information content of the materials include?

1. What sort of informational materials should be developed?
    a. Brochure
    b. Web site (referenced by brochure)
    c. Video demonstrating an STC system
    d. Talking points to accompany video (as a resource)
2. How may the information be disseminated to parents and/or teens?
    a. Motor vehicle administrations. MVAs have Web sites where parents may sign up their teens for learner permits and these sites may include tips and links to other sources. The STC Web site could be linked there. It may also be possible to make brochures available at MVA sites.
    b. NHTSA Web site, incorporation into NHTSA programs (e.g., NCAP)
    c. Safety organizations and foundations, motorist organizations (e.g., National Safety Council, AAA, Insurance Institute for Highway Safety)
    d. Schools.
    e. Driving schools.

f. Insurers.
g. Pediatricians.
h. Automobile dealerships.
i. PTAs and civic organizations. Video materials and talking points would be particularly relevant for these venues.
j. Local government or school-sponsored programs that relate to driving. For example, some areas require that the teen and at least one accompanying parent attend an informational session if the teen seeks to have parking privileges on school property.

3. What incentives can be included to motivate interest?
    a. Basic motivation is parental concern with the safety of their child. This is dealt with under item 4, below.
    b. Insurance discounts. Currently some insurers provide a discount for teens that are enrolled in certain programs of driving performance reporting and/or coaching based on video records (using after-market devices and services).
    c. School privileges, such as parking.
    d. Basis for effective parent/teen agreements, interactions, "teachable moments," granting privileges.
4. What should the information content of the materials include?
    a. Nature of the teen driving problem.
        i. High crash rates.
        ii. Factors we know are associated with increased rates (e.g., speed, distraction, peer passenger presence, night conditions).
    b. Benefit of adult presence in the vehicle – quite low crash rates.
        i. Adult provides a protective effect, encourages good driving behavior, discourages bad driving behavior.
        ii. Adult provides instruction, guidance, coaching.
    c. Technology can now stand in for the adult in some ways.
        i. Sensors can identify when risky driving or risk factors occur.
        ii. Real-time feedback can inform the teen of errors and inappropriate acts.
        iii. Some types of feedback or vehicle adaptation can also discourage intentional risky acts.
        iv. This type of technology use, when adapted as a system specifically designed to help teen drivers, has been shown to have benefits in terms of improved driving behavior (NHTSA research).
        v. This technology cannot replace adult supervision or do everything an adult passenger can do. But it can supplement and reinforce.
            1. Adult supervisor cannot always be there; technology can serve as a surrogate when no adult is present.
            2. An STC system provides a second, parallel type of feedback distinct from interaction with parent; "objective" and non-social outside expertise.
    d. What is a STC system?
        i. STC systems are now available in some vehicles.
        ii. The system recognizes when the teen is the driver (through programmable keys or other means). The STC system is only in effect when the teen is the driver; the vehicle operates as usual otherwise. An adult can override the activation of the STC system if they are present in the vehicle (where adult presence may be established through remote detection of an adult key or by other means).

iii. The STC system makes use of sensors and other information already present in the vehicle, in order to apply this information in a way that particularly benefits teen drivers. The STC capability is original equipment in vehicles and does not require additional products or enrollment in special programs. It is simply a feature of the vehicle that the responsible adult can control.
iv. The responsible adult controls the use of the STC and its options. A parent can decide whether or not to use it, when to discontinue using it, when to change system options. There is a broad spectrum of parents in terms of how they want to train and supervise their teen drivers and the use of the STC system can be adapted as the parent feels best.
v. The STC senses when certain risky behaviors and situations occur. The exact items sensed may vary among vehicles, but may include such things as speeding, seat belt use, driver distraction, excessive maneuvers (e.g., hard turns, severe braking), weather and road conditions, presence of passengers, and time of day (e.g., night driving). The system makes use of all of the information to determine when to issue various types of feedback to the driver.
vi. The STC system provides the driver with various types of feedback and adaption in real time (provide examples: speed alerts of various types, infotainment system lockout, etc.).
vii. An important aspect of the STC concept is that it adapts the feedback strategy to the current situation. For example, the level at which the driver gets a severe speeding alert will depend on such things as whether vehicle occupants are wearing seat belts or whether it is dark and rainy.
viii. The STC concept has demonstrated benefits in reducing risky behaviors by teen drivers (NHTSA research).

e. Considerations in selecting and using a vehicle with an STC system
   i. Different manufacturers may have STC systems that vary from one another. Vehicles may differ in terms of what driver behaviors and situational factors they deal with, what the exact form of the driver feedback or vehicle adaptation consists of, and what rules are employed for triggering feedback. (We anticipate that in addition to functions included in the present study, there soon may be in-place capabilities for sensing driver visual distraction, fatigue, impairment, or workload; all could be adapted for STC application).
   ii. One important consideration is that the system has the ability to recognize the local speed limit that is in effect wherever the vehicle is. While a STC system may set an absolute limit the maximum speed the vehicle can go with a teen driver, or a maximum speed at which a warning is always given, this is not adequate. It must be able to recognize *speeding* relative to the speed limit.
   iii. STC systems might differ in their tolerance for certain acts. Strict limits may have benefits but also may result in more nuisance alerts. Adaptive aspects of the system should help mitigate this. However, no system will be completely free of occasional nuisance alerts. For example, certain roadway situations could cause unnecessary alerts in certain systems (e.g., roundabouts may tend to be a source of unnecessary alerts in certain vehicles).
   iv. STC systems may differ in the adult supervisor's options for system operation and allow various degrees of personal customization and degree of control.
   v. Although the benefits of STC systems have been demonstrated, it is not well understood how long lasting the benefits are once the system is no longer used.

Parents may wish to pay special attention to teen driving if they terminate use of the system at some point.

vi. Provide here a list of vehicles offering STC.
    1. With indication of system features, if possible.
    2. With NCAP-type ratings or other consumer-oriented valuations, if possible.

6 References

Brookhuis, K., & de Waard, D. (1999). Limiting speed, towards an intelligent speed adaptor (ISA). *Transportation Research Part F: Traffic Psychology and Behaviour*, 2(2), 81-90.

Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J., & Knipling, R.R. (2006, April). *The 100-Car Naturalistic Driving Study. Phase II – Results of the 100-Car Field Experiment.* (Report No. DOT HS 810 593). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/Driver%20Distraction/100CarMain.pdf

Eby, D., Molnar, L., Kostyniuk, L., & Shope, J. (2004). *Developing an optimal in-vehicle safety belt promotion program.* (Report No. UMTRI 2004-29). Ann Arbor, Michigan: University of Michigan Transportation Institute.

Farmer, C., Kirley, B., & McCartt, A. (2010). Effects of in-vehicle monitoring on the driving behavior of teenagers. *Journal of Safety Research, 41,* 39-45.

Lerner, N., Jenness, J., Singer, J., Klauer, S., Lee, S., Donath, M., Manser, M., & Ward, N. (2010). *An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers.* (Report No. DOT HS 811 333). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Human%20Factors/Reducing%20Unsafe%20Behaviors/%EF%BB%BFDOT%20HS%20811%20333.pdf

Lerner, N., Singer, J., & Freedman, M. (2009). Enhanced seat belt reminder systems for teenage drivers and passengers. *Proceedings of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*. Iowa City, Iowa: University of Iowa.

Mayhew, D., Simpson, H., & Pak, A. (2003). Changes in collision rates among novice drivers during the first months of driving. *Accident Analysis and Prevention, 35,* 683-*691*.

McGehee, D., Raby, M., Carney, C., Lee, J., & Reyes, M. (2007). Extending parental mentoring using an event-triggered video intervention in rural teen drivers. *Journal of Safety Research, 38,* 215-227.

Ouimet, M., Simons-Morton, B., Zador, P., Lerner, N., Freedman, M., Duncan, G., & Wang, J. (2010). Using the U.S. National Household Travel Survey to estimate the impact of passenger characteristics on young drivers' relative risk of fatal crash involvement. *Accident Analysis and Prevention*, *42*, 686-694.

Simons-Morton, B., Ouimet, M., Zhang, Z., Klauer, S., Lee, S., Wang, J., Chen, R., Albert, P., & Dingus, T. (2011). The effects of passengers and risk-taking friends on risky driving and crashes/near crashes among novice teenagers. *Journal of Adolescent Health*, *49*, 587-593.

Van der Laan, J. D., Heino, A., & de Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research part C*, *5(1)*, 1-10.

This report also included information and data from unpublished reports delivered to NHTSA as interim Task Orders, as follows:

Edwards, C., Manser, M., Huey, R., Lerner, N., and Jenness, J. (2012). *An Evaluation of a Prototype Safer Teen Car: Document Final Specifications*. Report under Contract DTNH22-08-D-00115 TO 2.

Graving, J., Edwards, C., Manser, M., Easterlund, P., Lerner, N., Jenness, J., and Huey, R. (2011). *An Evaluation of a Prototype Safer Teen Car: Conduct Evaluation of Subsystems*. Interim project report under Contract DTNH22-08-D-00115 TO 2.

Gorjestani, A., Menon, A., Arpin, A., Cheng, P., Huey, R., Lerner, N., and Jenness, J. (2010). *An Evaluation of a Prototype Safer Teen Car: Determine Enabling Technologies that meet the Functional and Interface Specifications*. Interim project report under Contract DTNH22-08-D-00115 TO 2.

Manser, M., Edwards, C., Lerner, *N*., Jenness, J., & Huey, R. (2012). *An Evaluation of a Prototype Safer Teen Car: Specifications Document* Interim project report under Contract DTNH22-08-D-00115 TO 2.

Manser, M., Graving, J., Rakauskas, M., Creaser, J., Lerner, N., Jenness, J., & Huey, R. (2010a). *An Evaluation of a Prototype Safer Teen Car: Specify Subsystem Functions and their Performance Requirements*. Interim project report under Contract DTNH22-08-D-00115 TO 2.

Manser, M., Graving, J., Rakauskas, M., Lerner, N., Jenness, J., & Huey, R. (2010b). *An Evaluation of a Prototype Safer Teen Car: Develop and Review Data Collection and Analysis Plan*. Interim project report under Contract DTNH22-08-D-00115 TO 2.

Appendix A: Recruitment Flyer

TEEN PARTICIPANTS NEEDED FOR DRIVING STUDY

The University of Minnesota's HumanFIRST Program (www.humanfirst.umn.edu) is recruiting teens and their parent/guardian to help develop teen driver support systems. If you're a teen that received your license at least 6 months ago and are interested in participating, and have permission from a parent, the study requires that we install data recording equipment and a driver support system within your vehicle. As a teen participant, you would then drive for 10 weeks with this equipment in your car. You will be paid $25 after the installation of the Safer Teen Car system. Eight weeks after the installation date you will be paid $75. Finally, after an additional two weeks and at the end of the study you will receive $100. We would also ask that a parent/guardian be involved and we would pay them $50. Following the final two weeks of driving we would like to discuss what you and your parent/guardian thought of the driver support system.

To participate, **teens must**:

- Be 16 to 18 years of age,
- Must have obtained a valid provisional license, or full-privilege driver's license at least 6 months ago,
- Have 20/40 vision or better (corrected or not),
- Have no DUI or reckless driving violations, and
- Must drive a car or truck frequently (to school, work, friends' houses… etc.) and be willing to have the driver assistive system present within this vehicle for 10 weeks. The tires and wheels on your vehicle must be as close to the original sizes as possible. Persons with customized wheels and tires that are significantly larger or smaller than the original cannot participate in the study.
- Your car must be from 1996 or newer.

To participate, a **parent must**:

- Be the parent or legal guardian of the teen participating in the evaluation, and
- Possess a valid driver's license.

If you fit these criteria, you may be eligible to participate. If you are interested or would like more information, please have your parent contact **<insert name>** by phone at **<insert number>** or email at **<insert email>** (include "driving study" in the subject line). We will need your name and a phone number where your parent can be reached during the day. Upon confirming eligibility participants will be given further instructions.

Appendix B: Strong Warning Threshold Based on Posted Speed Limit and Other Contextual Elements

Posted Speed Limit (mph)	No violations	Seat belt violation	Three Passengers	Nighttime Driving
< 25 mph	+2 mph over	+2 mph over	+2 mph over	+2 mph over
25 mph	30 mph	32 mph	33 mph	27 mph
30 mph	40 mph	32 mph	36 mph	32 mph
35 mph	45 mph	37 mph	41 mph	37 mph
40 mph	50 mph	42 mph	46 mph	42 mph
45 mph	55 mph	47 mph	51 mph	47 mph
50 mph	65 mph	52 mph	60 mph	52 mph
55 mph	70 mph	57 mph	65 mph	57 mph
65 mph	80 mph	67 mph	75 mph	65 mph
70 mph	80 mph	72 mph	76 mph	72 mph
75 mph	80 mph	77 mph	78 mph	77 mph
80 mph	80 mph	80 mph	80 mph	80 mph

Appendix C: Parent/Guardian Consent Form

CONSENT FORM
An Evaluation of a Prototype Safer Teen Car
Task 6, Subtask: Full System Evaluations
Guardian Participant

You and your teen are invited to be in a research study to evaluate a proposed Driver Support System. The study is being sponsored by the National Highway Traffic Safety Administration (NHTSA). You were selected as a possible participant because your teen meets our eligibility requirements (aged 16 to 18, has had a driver's license for 6 or more months, uses a cell phone that matches our criteria). We ask that you read this form and ask any questions you may have before agreeing to be in the study, and allowing your teen to participate. Your teen must read and sign a separate consent form in order to participate. Signing this form indicates that you agree to allow your teen to participate.

In Minnesota, this study is being conducted by Michael Manser, Peter Easterlund, Justin Graving, Chris Edwards, and Janet Creaser who are research staff at the University of Minnesota's HumanFIRST program.

In Maryland, this Study is being conducted by Neil Lerner and Jim Jenness of Westat.

Background Information:
A significant number of teen drivers are involved in crashes during the first few years after getting a license. Research has shown that risky driving behaviors such as speeding or excessive maneuvers contribute to these crashes. In response, we have developed a Driver Support System, which may reduce the rate of risky driving behaviors by teens. The Driver Support System provides warnings if a driver carries out known risky behaviors. For example, the warnings will occur when the driver uses a cell phone, if the driver exceeds the speed limit, if the driver is not buckled, or if the driver accelerates aggressively." The purpose of the study is to determine if the Driver Support System does assist teens in reducing risky driving behaviors

Procedures:
We are asking that you allow us to install the Driver Support System within your teens primary vehicle. After the system is installed your teen should drive as he or she would normally and respond to the system feedback as he or she sees fit. We want to measure the way your teen drives while the Driver Support System is activated (providing feedback) and when it is not activated (not providing feedback). At the end of the study we want to hear what you and your teen think of the system. At the end of the study we will examine the data from the Driver Support System to see if the system changed the way your teen drove.
If you agree to be in this study the following items will be required:

1. Allow us to test the battery and alternator in your teen's vehicle:
    a. You must replace your battery if it does not meet our criteria. We will provide an allowance to purchase a new battery for your car under such circumstances
    b. If the alternator does not meet our criteria you will not be allowed to participate.
2. Provide us with your teen's cell phone number and the name of the GSM cell phone carrier;

3. Allow us to install the prototype Driver Support System within your teen's primary vehicle (whether it's your or your teen's vehicle). In Minnesota, the installation will occur at the University of Minnesota. In Maryland the installation will occur at Westat Facilities in Rockville;
    a. The Driver Support System uses power from your car battery and it may drain power from your teen's car battery if it is not charged nightly;
    b. A battery drained of its power may result in your teen not being able to start his or her car;
    c. We will install a device called a Battery Tender within your vehicle that can be used to charge your vehicle.
4. Allow your teen drive for a two week "**Baseline**" period. The Driver Support System will not be active but it will be collecting data on driving behavior;
5. We want to meet with you or your teen at your house periodically throughout the duration of this study. These meetings allow us to check the Driver Support System to make sure it is working correctly; the meetings also allow us to activate or deactivate the system;
6. After baseline, allow your teen to drive for six more weeks for a "**Treatment**" period during which the Driver Support System will be active. When the system is active it will provide feedback regarding driving behavior;
7. After the treatment period, we want your teen to drive for an additional two weeks for a "**Post-treatment**" phase during which the system will be deactivated but we will continue measuring driving behavior;
8. After the study we want to talk to you and your teen to talk about what you both think of the system. We will uninstall the Driver Support System during this meeting.

The total amount of time required to complete this study is approximately 10 weeks. There may be a few extra days for waiting to have the system installed or uninstalled that could cause your participation to exceed 10 weeks. The Driver Support System will be present within your teen's vehicle throughout the duration of the study, and we are asking your teen to drive as he or she would normally throughout the duration of the study.

Risks and Benefits of being in the Study:

There are no direct benefits to you or your teen for participating in this study. However, you may gain some insight into your teen's driving style. Your teen will not be asked to do any extra driving in addition to how much he or she normally drives. Be aware that regular driving has some level of risk. Your teen is responsible for driving safely during this study. The extent the Driver Support System contributes to driver distraction is unknown; there may be risk that the features may distract the driver when this system is activated. There is also an unknown amount of risk of theft or vandalism involved in leaving a car unattended with the Driver Support System installed. This risk may be similar to that of having a navigation system, like a Garmin, in your car.

Compensation:

Your teen will receive $25 after we install the system the first day of the study, $75 after the treatment period eight weeks after the installation date, and $100 when the study is over after the full ten weeks. Partial incentive will occur if your teen decides to opt out of the study during any of the phases.

You will receive your total incentive of $50 at the end of the study at 10 weeks. However, even if you and your teen decide to stop participating in the study you will still receive the full incentive of $50.

For your teen to receive his or her full incentive you and your teen must remain participants throughout the entire duration of the study.
You must agree to participate in order for your teen to participate in the study. If you withdraw at any time your teen will not be able to continue participating.

Confidentiality:
You and your teen's personal information, such as your name, phone number, address, etc. will not be associated with the data obtained from the vehicle data acquisition system. We will assign an identification number to all your data rather than using your name or other personal identifiers.

The records of this study will be kept private. In any sort of report we might publish, we will not include any identifying information that will make it possible to identify a participant. Identifying information collected in this study includes your contact information, your individual responses to questionnaires and interviews, your driving data (including GPS coordinates that may identify your home, work, or school locations), or any other information in your driver data, vehicle data, or additional crash data that could be used to personally identify you or your teen. Research records will be stored securely and only researchers will have access to the records. Your name and the name of your teen will not be shared with the study sponsor (NHTSA).

Staff members from Westat and the University of Minnesota are the only people that will have access to the data collected from this study. During the study data will be obtained from the Driver Support System using a laptop. At the end of data collection the data will be removed from the laptop and stored on an encrypted external hard drive. The encrypted hard drive that contains data collected in Maryland may be shipped to Mike Manser of the University of Minnesota. The encrypted hard drive that contains data collected in Minnesota may be shipped to Jim Jenness or Neil Lerner from Westat. The external hard drive and the hard drive on the laptop will be wiped clear of all data prior to disposing of them.

Neither University of Minnesota nor Westat will be responsible if participants experience injury or damages as a result of a crash during the study period. You must provide appropriate automobile insurance coverage during the study period. Your insurance will be expected to pay for injury or damages as a result of a crash during the study period. Neither University of Minnesota nor Westat will be responsible for injuries that are not the fault of the investigators.

Information about the Certificate of Confidentiality:
We will do everything we can to keep others from learning about your participation in this study. To further help us protect your privacy, we have obtained a Certificate of Confidentiality from the United States Department of Health and Human Services (DHHS). With this certificate, we cannot be forced (for example by court order or subpoena) to disclose information that may identify you in any federal, state, local, civil, criminal, legislative, administrative, or other proceedings. Parents or legal guardians have the right to information regarding a minor child, unless an Institutional Review Board has approved the study with a waiver of parental permission. You should understand that a Certificate of Confidentiality does not prevent you, or a member of your family, from voluntarily releasing information about yourself, your child, or your involvement in this study. The researchers

however, will not disclose voluntarily, or without your consent, information that would identify you or your child as a participant in this research project.

Researchers do not plan to share your child's driving data with you as part of the study. However, if your child (participant) is less than 18 years old, you have a right to obtain his or her data. In the event that your child is involved in a crash or other emergency situation, researchers will share information with you if you request it.

If an insurer or employer learns about your participation, and obtains your consent to receive research information, then we may not use the Certificate of Confidentiality to withhold this information from them. This means that you and your family must also actively protect your own privacy!

You should understand that we will in all cases, take the necessary action and report to authorities, any indication of abuse, and to prevent serious harm to yourself, your child, or others as in the case of child abuse or neglect. The Certificate of Confidentiality also does not prevent researchers from disclosing information or taking steps to prevent serious harm to your child or others. These steps may include contacting you or law enforcement authorities. Harmful behaviors may include extreme habitual aggressive or reckless driving. If this type of behavior is observed, we reserve the right to remove your child from the study and to inform appropriate authorities of what we observed. If your child is removed from the study, his or her compensation will be prorated based on the time already spent in the study.

While your confidentiality is protected in most cases by the Certificate of Confidentiality, you should know that in some rare instances a court or agency may prevent you from asserting a claim, or a defense to a claim that someone has brought against you, unless you waive confidentiality and allow access to your data.

The protections of the Certificate of Confidentiality may not apply to passengers or drivers of your vehicle who have not consented to being in this study.
The Certificate of Confidentiality does not mean that the Department of Health and Human Services or the National Institutes of Health endorses this study.

Voluntary Nature of the Study:
Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota, Westat, or the National Highway Traffic Safety Administration (NHTSA). If you decide to participate, you are free to not answer any question. You can withdraw from this study at any time. Your teen's compensation will be adjusted according to when you withdraw, for example, if you withdraw during baseline you will not receive the full incentive amount.

Contacts and Questions:
You may ask any questions you have now. If you have questions **later**, you are encouraged to contact the lead researcher at your particular location:

- Minnesota: Michael Manser at [redacted]
- Maryland: Neil Lerner at [redacted]

If you have any questions or concerns regarding this study and would like to talk to someone **other than the researcher(s)**, you are encouraged to contact the Research Subjects' Advocate Line, [redacted]

Statement of Consent:
I have read the above information. I have received answers to my questions. I consent to participate in the study. I understand that I will be given a copy of this consent form to keep for my records.
Signature:____ Date: _________________

Signature of Investigator:______________________________ Date: _________________

Appendix D: Teen Assent Form

ASSENT FORM

An Evaluation of a Prototype Driver Support System –
Task 6, Subtask: Full System Evaluation
Teen Participant

You and your parent/guardian are invited to be in a research study to evaluate a Driver Support System . The study is being sponsored by the National Highway Traffic Safety Administration (NHTSA). You were selected as a possible participant because you are 16 to 18 years old, you obtained your driving license at least 6 months ago, and you have an approved cell phone (your cell phone must match our criteria). We ask that you read this form and ask any questions you may have before agreeing to be in the study. Your parent will read and sign a separate consent form. Your parent must agree in order for you to participate in this study.

In Minnesota, this study is being conducted by Michael Manser, Peter Easterlund, Justin Graving, Chris Edwards and Janet Creaser who are research staff at the University of Minnesota's HumanFIRST program. In Maryland, this study is being conducted by Neil Lerner and Jim Jenness of Westat.

Background Information

A significant number of teen drivers are involved in crashes during the first few years after getting a license. Research has shown that risky driving behaviors such as speeding or excessive maneuvers contribute to these crashes. In response, we have developed a Driver Support System, which may reduce the rate of risky driving behaviors by teens. The Driver Support System provides warnings if a driver carries out known risky behaviors. For example, the warnings will occur when the driver uses a cell phone, if the driver exceeds the speed limit, if the driver is not buckled, or if the driver accelerates aggressively." The purpose of the study is to determine if the Driver Support System does assist teens in reducing risky driving behaviors.

Procedures:

We are asking that you allow us to install the Driver Support System within your primary vehicle. After the system is installed you should drive as you would normally and respond to the system feedback as you see fit. We want to measure the way you drive while the Driver Support System is activated (providing feedback) and when it is not activated (not providing feedback). Your parent is also a participant in the study. At the end of the study we want to hear what you and your parent think of the system. At the end of the study we will examine the data from the Driver Support System to see if the system changed the way you drove.

If you agree to be in this study the following items will be required:

1. Allow us to test your vehicle battery and alternator:
    a. You must replace your battery if it does not meet our criteria. We will provide an allowance to purchase a new battery for your car under such circumstances;
    b. If the alternator in your vehicle does not meet our criteria, you will not be allowed to participate.
2. Provide demographic and driving history information;
3. Provide your cell phone number and the name of your cell phone carrier;

4. Allow us to install the Driver Support System in your primary car or truck. In Minnesota, the installation will occur at the University of Minnesota in Minneapolis. In Maryland the installation will occur at Westat Facilities in Rockville:
    a. The Driver Support System uses power from your car battery, and it may drain power from your car battery if you do not charge your car battery nightly;
    b. A battery drained of its power may result in you not being able to start your car;
    c. We will install a device called a Battery Tender within your vehicle that can be used to charge your vehicle.
5. Drive your vehicle for a two week "**Baseline**" period. During baseline the Driver Support System will not be active but it will be collecting data. You should drive as you would normally;
6. We want to meet with you at your house periodically throughout the duration of this study. These meetings allow us to check the Driver Support System to make sure it is working correctly; the meetings also allow us to activate or deactivate the system;
7. After baseline, we want you to drive for six more weeks for a "**Treatment**" period during which the Driver Support System will be active. When the system is active it will provide feedback on your driving. During this period you should drive as you would normally while also using the information provided by the Driver Support System as you see fit;
8. After the treatment, we want you to drive for an additional 2 weeks for a "**Post-treatment**" phase during which the system will be deactivated but we will continue to measure your driving behavior;
9. After the study we want to talk to you and your parent to talk about what you both think of the system. We will uninstall the Driver Support System during this meeting.

The total amount of time required to complete this study is approximately 10 weeks. There may be a few extra days for waiting to have the system installed or uninstalled that could cause your participation to exceed 10 weeks. The Driver Support System will be present within your vehicle throughout the duration of the study, and we are asking you to drive as you would normally throughout the duration of the study.

Risks and Benefits of Being in the Study:

There are no direct benefits to you for participating. You may gain some insight into your driving style that may help you be safer. You will not be asked to do any extra driving in addition to what you normally drive. Be aware that regular driving has some level of risk. You are responsible for driving safely during this study. The extent the Driver Support System may distract you is unknown; there may be risk that you become distracted when this system is activated. There is also an unknown amount of risk of theft or vandalism involved in leaving a car unattended with Driver Support System installed. This risk may be similar to that of having a navigation system, like a Garmin, in your car.

Compensation:

In appreciation for your time and participation in the 10 week study you will receive $25 after we install the system the first day of the study, $75 after the treatment period eight weeks after installation, and $100 when the study is over after the full 10 weeks. You will receive partial payment if you decide to opt out of the study during any of the phases.

Your parent will receive a single incentive of $50 in appreciation for his or her time and participation in the study after the 10 weeks. Your parent will receive the full incentive amount ($50) even if you and your parent decide to stop participating in the study.
Your parent must consent to participate in the study; if your parent withdraws at any time you will not be able to continue participating.

Confidentiality:
You and your parent's personal information, such as your name, phone number, address, etc. will not be associated with the data obtained from the vehicle data acquisition system. We will assign an identification number to your data rather than using your name or other personal identifiers.
The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify you as a participant. Identifying information for the purposes of this study includes your contact information, your individual responses to questionnaires and interviews, your driving data (including GPS coordinates that may identify your home, work, or school locations), or any other information in your driver data, vehicle data, or additional crash data that could be used to personally identify you. The data from this study will be stored securely and only researchers will have access. Your name will not be shared with the study sponsor (NHTSA).

Staff members from Westat and the University of Minnesota are the only people that will have access to the data collected from this study. During the study data will be obtained from the Driver Support System using a laptop. At the end of data collection the data will be removed from the laptop and stored on an encrypted external hard drive. The encrypted hard drive that contains data collected in Maryland may be shipped to Mike Manser of the University of Minnesota. The encrypted hard drive that contains data collected in Minnesota may be shipped to Jim Jenness or Neil Lerner from Westat. The external hard drive and the hard drive on the laptop will be wiped clear of all data prior to disposing of them.

Neither University of Minnesota nor Westat will be responsible if participants experience injury or damages as a result of a crash during the study period. The participant's family must provide appropriate automobile insurance coverage during the study period. The participant's (parent's) insurance will be expected to pay for injury or damages as a result of a crash during the study period. Neither University of Minnesota nor Westat will be responsible for injuries that are not the fault of the investigators.

Information about the Certificate of Confidentiality for this Study:
We will do everything we can to keep others from learning about your participation in this study. To further help us protect your privacy, we have obtained a Certificate of Confidentiality from the United States Department of Health and Human Services (DHHS). With this certificate, we cannot be forced (for example by court order or subpoena) to disclose information that may identify you in any federal, state, local, civil, criminal, legislative, administrative, or other proceedings. Parents or legal guardians have the right to information regarding a minor child, unless an Institutional Review Board has approved the study with a waiver of parental permission. You should understand that a Certificate of Confidentiality does not prevent you, or a member of your family, from voluntarily releasing information about yourself, or your involvement in this study. The researchers however, will not disclose voluntarily, or without your consent, information that would identify you or your parent as a participant in this research project.

Researchers do not plan to share your driving data with your parents as part of the study. However, if you are less than 18 years old, your parent or legal guardian has a right to obtain your data. In the event that you are involved in a crash or other emergency situation, researchers will share information with your parent or guardian if they request it.

If an insurer or employer learns about your participation, and obtains your consent to receive research information, then we may not use the Certificate of Confidentiality to withhold this information. This means that you and your family must also actively protect your own privacy!
You should understand that we will in all cases, take the necessary action and report to authorities, any indication of abuse, and to prevent serious harm to yourself, your parent, or others as in the case of child abuse or neglect. The Certificate of Confidentiality also does not prevent researchers from disclosing information or taking steps to prevent serious harm to yourself or others. These steps may include contacting your parents or law enforcement authorities. Harmful behaviors may include extreme habitual aggressive or reckless driving. If this type of behavior is observed, we reserve the right to remove you from the study and to inform appropriate authorities of what we observed. If you are removed from the study, your compensation will be prorated based on the time you have already spent in the study.

While your confidentiality is protected in most cases by the Certificate of Confidentiality, you should know that in some rare instances a court or agency may prevent you from asserting a claim, or a defense to a claim that someone has brought against you, unless you waive confidentiality and allow access to your data.
The protections of the Certificate of Confidentiality may not apply to passengers or drivers of your vehicle who have not consented to being in this study.
The Certificate of Confidentiality does not mean that the Department of Health and Human Services or the National Institutes of Health endorses this study.

Voluntary Nature of the Study:
Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota, Westat, or the National Highway Traffic Safety Administration (NHTSA). If you decide to participate, you are free to not answer any question. You can withdraw from this study at any time. Your compensation will be adjusted according to when you withdraw from this study, for example, if you withdraw during baseline you will not receive the full incentive amount.

Contacts and Questions:
You may ask any questions you have now. If you have questions **later**, you are encouraged to contact the lead researcher at your particular location:

- Minnesota: Michael Manser at [redacted]
- Maryland: Neil Lerner at [redacted]

If you have any questions or concerns regarding this study and would like to talk to someone **other than the researcher(s)**, you are encouraged to contact the Research Subjects' Advocate Line, [redacted].

Statement of Assent:
I have read the above information. I have received answers to my questions. I consent to participate in the study. I understand that I will be given a copy of this assent form to keep for my records.
Signature:____ Date: ___________________

Signature of Investigator:__________________________________ Date: ___________________

Appendix E: Total Miles and GPS Miles Traveled and RFID Marked Miles

Location	Participant	Total miles (With Parental RFID card)		GPS Miles (With Parental RFID card)		Percent of GPS miles excluded[1]
Minnesota	101	3,677	(1,343)	2,964	(1,194)	40.3%
	102	1,149	(42)	705	(24)	3.4%
	103	1,127	(3)	840	(2)	0.2%
	104	4,964	(1,187)	3,026	(719)	23.8%
	105	2,769	(17)	1,835	(13)	0.7%
	106	1,073	(196)	838	(160)	19.1%
	107	2,894	(1,073)	2,036	(604)	29.6%
	108	1,728	(17)	1,308	(11)	0.9%
	109	715	(583)	530	(442)	83.4%
	199	1,289	(24)	964	(19)	2.0%
	198	1,381	(197)	975	(142)	14.6%
	197	1,623	(196)	1,253	(169)	13.5%
	195	4,354	(880)	1,729	(700)	40.5%
	194	1,431	(4)	1,090	(4)	0.4%
Maryland	350	508	(29)	330	(23)	7.0%
	351	978	(20)	713	(14)	2.0%
	352	589	(0)	303	(0)	*
	353	1,201	(667)	1,035	(632)	61.1%
	354	334	(6)	212	(4)	1.7%
	355	1,586	(211)	1,178	(166)	14.1%
	356	1,164	(93)	967	(73)	7.6%
	357	618	(3)	475	(1)	0.3%
	358	893	(0)	518	(0)	*
	359	1,156	(4)	870	(2)	0.2%
	360	630	(0)	399	(0)	*
	361	684	(0)	462	(0)	*
	362	439	(21)	235	(16)	6.8%
	363	1,722	(74)	140	(35)	25%
	364	943	(0)	727	(0)	*
	TOTAL	43,619	(6,890)	28,657	(5,169)	18%

Note: [1]GPS miles excluded are those miles that a parental RFID card is detected and the system identifies valid miles, however driver type cannot be identified.
**denotes that there were zero miles with an RFID card.*

Appendix F: Vehicle Miles Traveled Night and Day by Teens

Condition	Participant	Day Miles	Night Miles
Minnesota	101	864	201
	102	893	441
	103	331	109
	104	872	327
	105	3,298	593
	106	685	235
	107	1,381	358
	108	2,214	559
	109	78	58
	199	1,078	198
	198	466	298
	197	682	240
	195	927	508
	194	1,989	370
Maryland	350	656	147
	351	864	413
	352	619	337
	353	672	312
	354	404	130
	355	1,237	491
	356	1,330	615
	357	448	256
	358	774	448
	359	1,090	272
	360	356	222
	361	720	154
	362	542	154
	363	782	685
	364	994	305
	TOTAL	28,216	9,909

Appendix G: Combined Minnesota and Maryland Responses during the Unstructured Interview

System	Category	Comment
Speed	Awareness	"It made me aware of the speed limit and will encourage drivers to stay below it."
	Concerns	"If the computer displays the wrong speed limit, perhaps the insurance company will increase my rates even though I am not speeding."
	Distraction	"Distracting while navigating heavy traffic." "It would yell at me when I accelerated to pass a car."
	Following system instructions	"The speed warnings were not appropriate on the highway, because it is not safe to go below the speed of traffic"
	Positive	"I liked having a constant reminder of the speed limit" "I liked having it for unfamiliar roads" "I prefer to have the system yell at my son rather than me"
	Reliability	"It displayed the wrong speed limit from time to time" "It briefly displayed the speed limit of a highway I had just passed under, rather than the road I was driving on" "It would not adjust quickly enough while accelerating onto a highway."
	System Change	"Time delay needed for passing cars and making speed adjustments" "Need more flexibility with the speed limit" "Change icon color to be green for right speed, yellow for a little bit over, and red for persistently over or a high amount over." "The computer should tell me what speed it thinks I'm going so I can check the accuracy against my own speedometer." "Make the speed warning tone longer and more jarring" "2-3 mph over the limit is not realistic." "I want a dual system to display my speed and the speed limit side by side simultaneously"
	Awareness	"I buckled the seat belt right away so the computer wouldn't harass me"
Seat belt	Distraction	"Bags/objects on the seat would activate the warning"
	Positive	"I'm glad the system reminded the passengers to buckle their seat belts so I wouldn't have to yell at them"
	Reliability	"Passenger side seat belt warning went off when there were no passengers" "I heard the 'driver buckle seat belt" warning when the car was off and no key was in the ignition"
	System Change	"Add a seat cover for the driver to prevent false warnings when warming up the car but not actually sitting in the car" "Have higher weight threshold for the rear seats" "Have an override system if there are objects on the seats" "The system should identify each particular passenger who does not have their seat belt buckled" "Seat belt warnings should only be activated after the car is taken out of park"
Maneuver	Awareness	"I would go more slowly around corners in order to avoid the tone."
	Distraction	"The 10 second tone was too long" "Kept going off nonstop for the first two weeks, but then it was repaired" "It would not stop beeping no matter what I did" "Sometimes the maneuver warning went off when I was driving in a straight line and wasn't turning" "It would activate after being stopped at a stop sign and executing a turn" "It would beep at me during normal acceleration" "There was one incident when it kept going off for five minutes straight no matter what I did" "It would go off if somebody accidently kicked the computer under the seat" "It was too sensitive and would activate on roundabouts"
	Positive	"This is an important system to have in the car" "It is good for beginning drivers." "I like the aggressive maneuver warning because it's just a tone and doesn't nag me"

	System Change	"I want more flexibility in maneuvering around corners and roundabouts" "There is too big of a delay between the maneuver and the warning. It should warn the driver while he does a maneuver, not afterwards." "The tone should be 5 seconds long, not 10" "There should be two settings: mild and extreme" "The maneuver icon's tire tracks do not actually match up with the car motion" "The maneuver warning should be a voice and not a tone" "The volume should be adjustable"
Context	Awareness	"I noticed the system was more sensitive at night" "I needed to drive slower at night so it wouldn't beep"
	System Change	"It is too strict at night and the speeding threshold should be increased" "It is not strict enough at night" "There should be a light detector for when it is dark and cloudy" "It would be great if it could detect rain or snow or ice"
Driver ID	Reliability	"I could easily grab my parent's card if I wanted to" "The car didn't detect the card on more than one occasion" "Sometimes we would drive a few blocks before the screen popped up"
	Distraction	"I sometimes forgot the card at home" "The card is a hassle to keep track of" "We would forget to switch the cards with each other"
	System Change	"A pin number could be used to identify the driver" "We could have special keys in order to tell who is driving" "More cards are needed so that each driver has one" "The display needs to be longer than 5 seconds for us to choose" "The default state should be 'adult,' and the teen should identify himself"

Appendix H

Evaluation of a Prototype Safer Teen Car: Determine Enabling Technologies That Meet the Functional and Interface Specifications

Task 2 Interim Report

Submitted to:

National Highway Traffic Safety Administration
1200 New Jersey Avenue SE.
Washington, DC 20590

Submitted by:

Alec Gorjestani, Arvind Menon, Eddie Arpin, and Pi-Ming Cheng
Intelligent Vehicles Laboratory
1100 ME, 111 Church Street SE.
University of Minnesota
Minneapolis, MN 55455
and

Richard Huey, Neil Lerner, and James Jenness
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1600 Research Blvd.
Rockville, MD 20850

This appendix can be cited separately using the following suggested APA format citation:

Gorjestani, A., Menon, A., Arpin, E., Pi-Ming, C., Huey, R., Neil Lerner, N., & Jenness, J. (2013, February). Evaluation of a prototype safe teen car: Determine enabling technologies that meet the functional and interface specifications. (Appendix H). In Michael Manser, Christopher Edwards, Neil Lerner, James Jenness, & Richard Huey, *Evaluation of a Prototype Safer Teen Car*. (Report No. DOT HS 811 784). Washington, DC: National Highway Traffic Safety Administration.

Table of Contents

Table of Pictures

1. Background and Objective

The current project addresses the serious problem of risky teen driving behaviors that may contribute to crashes during the first few months of licensure. The goal of the project is to develop and evaluate a teen driver support system (Safer Teen Car) that will motivate teens to reduce risky driving behaviors by providing feedback about risky behaviors and provide vehicle adaptations. To accomplish this goal, the project will consist of eight tasks that include:

Task 1: Specify subsystem functions and their performance requirements;

Task 2: Determine enabling technologies that meet the functional and interface specifications;

Task 3: Develop and review data collection and analysis plan;

Task 4: conduct evaluation of subsystems;

Task 5: Build and demonstrate to NHTSA the prototype car;

Task 6: Conduct stakeholder outreach and prototype vehicle evaluations, develop parent/teen information program;

Task 7: Document final specifications; and

Task 8: Generate final report, conduct stakeholder meetings.

This purpose of Task 2 is to analyze the proposed subsystems in Task 1 for their technical feasibility in deployment in a field operational test. Technologies with the best combination of cost, performance and simplicity of installation were then selected to form the basis of the Safer Teen Car system to be deployed in 15 vehicles in the Washington, DC, metropolitan area and 15 vehicles in the Twin Cities metropolitan area.

2. Subsystem Technical specifications

In Task 1, Manser et al. divided the Safer Teen Car system into seven subsystems that provide driving feedback (directly or indirectly). The systems will be analyzed individually to determine the technical capabilities required to deliver the subsystem functionalities. Then, "vehicle packs" that provide subsystem functionality will be designed and presented for evaluation.

2.1. Teen Driver Identification Subsystem

The goal of TDIS is to identify whether a teen or parent is driving. This subsystem allows the parent to opt-out of the Safer Teen Car warnings if so desired. If the parent is not in the car, the Safer Teen Car system will be active by default. Since the opt-out is only allowed when the parent is in the vehicle, only the parent needs be detected.

There are numerous biometric technologies available that vary in cost, reliability and practicality in a FOT. The University of Minnesota Intelligent Vehicles Lab (IVLAB) considered the following technologies for their use in the STC vehicle pack.

2.1.1. Biometric fingerprint identification

In this technology, the driver must place or drag their finger across a sensor that takes an image of the finger. Analysis software looks for signatures in the fingerprint that uniquely identify the person. Fingerprint readers are becoming common in laptop computers as a way to identify the user for operating system privileges. The cost of fingerprint readers is reasonable and many have built in processors that take care of the signature identification making them easy to use. The identification is reliable. This technology does add complexity to the startup process as the system must ask the user to swipe his/her finger. It also poses some practical challenges because the finger print reader must be securely mounted in the participants' vehicle without damaging or altering the vehicle interior trim.

2.1.2. Voice recognition

Voice recognition technology consists of a microphone and a signal processor that analyzes voice patterns to identify a driver. The microphone hardware is inexpensive, but the processing hardware can be more costly. The performance of the system is dependent upon the quality of the microphone, the level of ambient noise, and the quality of the recognition software. In a vehicle, where ambient noise levels are unpredictable, the practicality of voice recognition is questionable. Also, the mounting requirements of the microphone (especially if it must be close to the driver) may prove impractical.

2.1.3. Facial recognition

Facial recognition technology uses a camera, image capturing hardware, and image processing software to determine the identity of a driver using unique facial features. The hardware is relatively costly because the processing requirements are high. The performance of the system in a vehicle is questionable due to the varying light conditions (day, sun, night). The technology also poses practical challenges because a camera has to be nondestructively yet securely mounted in the participant's vehicle with a good view of the driver's face.

2.1.4. Passwords

Password technology is mature and requires an input device, usually an alphanumeric keypad (physical or virtual). This technology is only reliable if the password is not shared, decipherable by entry observation, and is not easily guessable. This technology is inexpensive and practical for the Safer Teen Car because a touch screen display will be present for the implementation of the warnings subsystems.

2.1.5. Eye Scan

There are predominantly two types of eye scans; retinal and iris. Both use a visual scan of the eye to locate signatures unique to individuals. The reliability of the identification is high. For an FOT, the practicality of installation is low because an eye scanner has to be nondestructively mounted in a participant's vehicle.

2.1.6. Electronic key

An electronic key emits a digital signature to the car that identifies the key. This technology is becoming ubiquitous in new vehicles. The technology is inexpensive. It is reliable unless the key is borrowed or stolen. Generally, the method by which an electronic key is integrated into a vehicle makes it impractical for an FOT. However, an analogous system that mimics the behavior of the electronic key is radio frequency identification. In this system, a transceiver sends a radio frequency signal that is echoed back by a passive tag or signal is sent by an active tag. The transceiver can be installed underneath the dash-board and the tag can be attached to the key chain. This makes installation in an FOT practical.

A summary of the cost, performance and FOT practicality of each of the discussed technologies is shown in Table 15. The two technologies that have a high rating for FOT practicality are passwords and electronic key. Passwords would not require additional hardware installation but would require additional software development. It would also require an additional setup procedure as the teenager and/or parents would have to set their passwords. Using RFID to emulate an electronic key would require installation of a transceiver in the vehicle pack and an RFID tag would be given to the parent. Since only the parent would need to be identified, the system can be preconfigured and the tag programmed with the parent identification. This would eliminate the need for configuration. The system also requires no action by the parent or teen because the tag is automatically recognized when it enters the vehicle. This makes it easy to use. For these reasons, the TDIS subsystem will use RFID technology to identify the parent in the vehicle. Pragmatically, this may have potential as an OEM solution as well, avoiding some of the cost and limitations of a MyKey-like system.

Table 13: Summary of available driver recognition technologies. A comparison on cost, performance and FOT practicality are estimated.

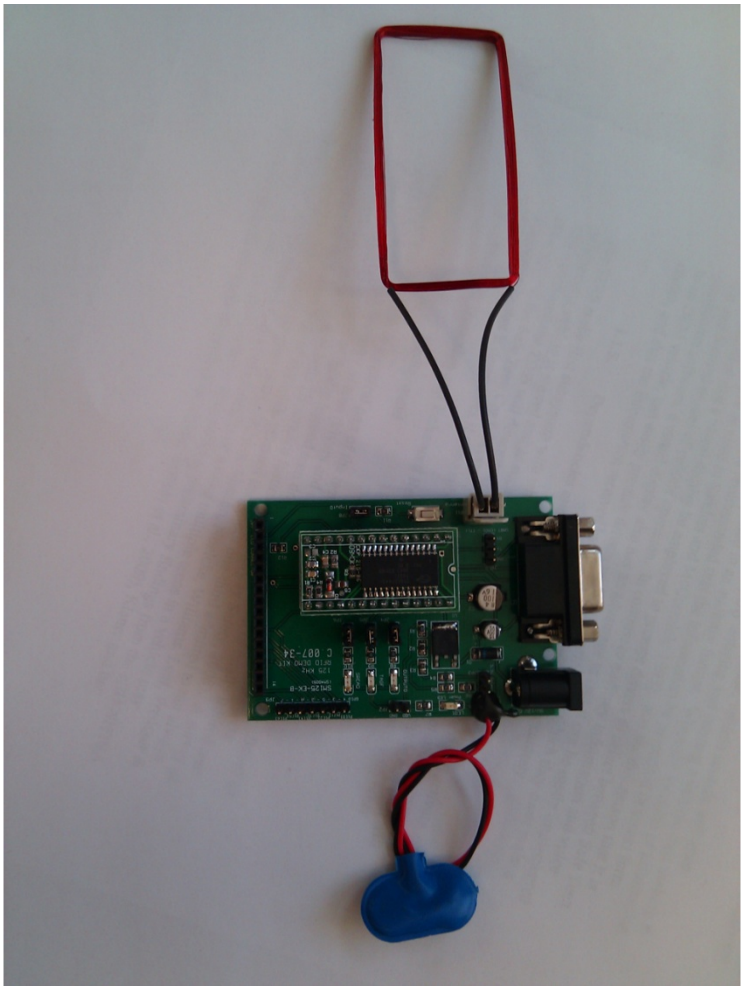
Technology	Cost	Performance	FOT Practicality
Fingerprint	$$	High	Medium
Voice	$$$	Low	Medium
Facial	$$$	Low	Low
Passwords	$	Medium	High
Eye Scan	$$$	High	Low
Electronic Key	$$	Medium	High

2.2. Seat Belt Detection and Enhance Reminder Subsystem

The functional requirement of seat belt detection is to sense whether the seat belt is buckled. One way to sense the seat belt latch is to take the seat belt apart and tap into the latch switch. This is not feasible in a FOT in which every vehicle could be a different make and model. It was desirable to not limit the FOT to a few vehicle make/models. Thus, a generic non-intrusive technology for detecting the seat belt closure was needed.

2.2.1. Radio Frequency Identification

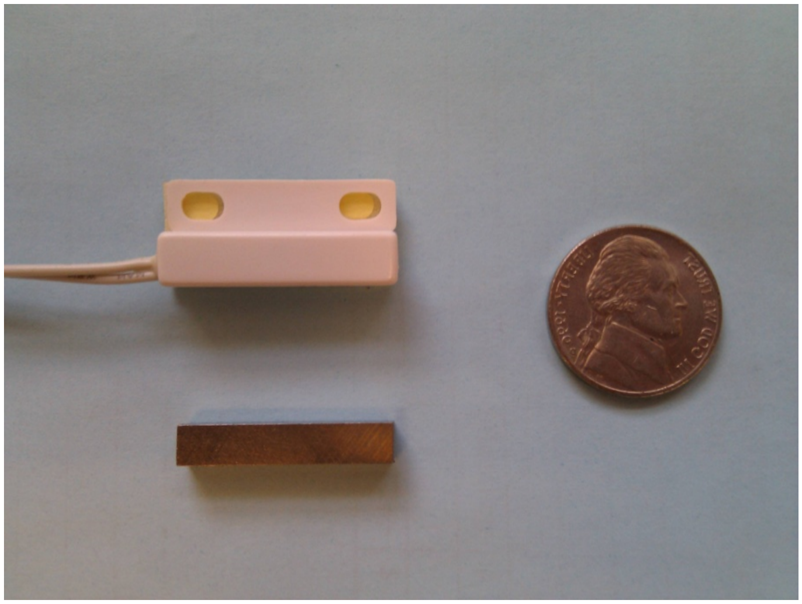
The first technology investigated was RFID (see Picture 1). The tag could be adhered to the belt buckle and the reader antenna could be attached to the seat belt receptacle. A low frequency (LF, 125 KHz) RFID reader was acquired to determine if it had sufficient read range for the seat belt detection application. The reader had two centimeter range when the RFID tag was located within the wire coil of the antenna. However, in the seat belt detection application, the RFID tag would be outside the antenna coil. In this situation, the read range was less than one cm. This small range makes it impractical because mounting the RFID on the buckle in a manner that brought it less than 1 cm to the antenna would be difficult. Also, RFID readers are not as cost effective as other technologies and were thus eliminated from consideration.



Picture 1: Low frequency RFID transceiver with external antenna (top) and battery pack connector (bottom)

2.2.2. Reed switch

A reed switch closes when a magnetic field of sufficient strength is present. The magnetic field is provided by a magnet brought into proximity with the switch. This is a mature and widely used technology in a variety of industrial and security applications. An advantage of the reed switch is that it requires no external power and is very reliable. The IVLAB acquired several types of reed switches to test their switching range with various magnet sizes and types. The experiments confirmed that a reed switch is a viable alternative for seat belt detection. The 0938C reed switch made by Honeywell (Picture 2) showed 3 cm range with a one inch long 0.19 inch square magnet. The switch was also relatively insensitive to offset, inexpensive (<$10), and does not require power. Installation should be fairly straight forward. The magnet can be adhered to the buckle and the switch adhered to the receptacle using industrial-grade double stick tape and/or heat-shrinkable tubing. For these reasons, the Honeywell 0938C reed switch was selected to sense seat belt engagement for the FOT.


Picture 2: Honeywell reed switch and magnet

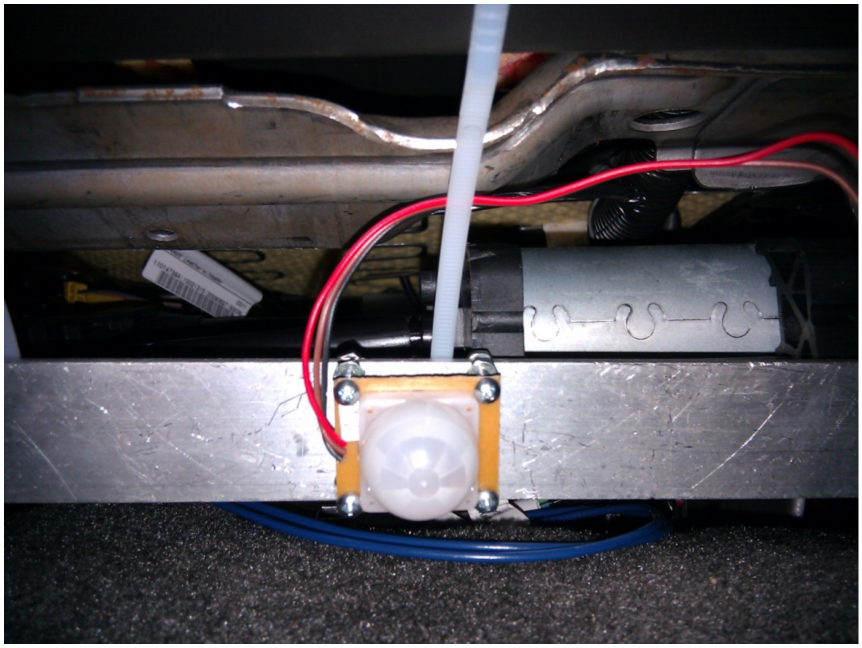
2.3. Passenger Presence Subsystem

Detecting the presence of passengers is a difficult problem in the FOT because the seat cannot be permanently altered. Traditionally, the IVLAB has used piezoelectric strips embedded in the seat to provide presence detection for its dedicated, instrumented vehicles. This requires taking the seat cover off, which is time consuming and somewhat damages the seat material. This approach was ruled out for this FOT.

Other sensing ideas were considered but ruled out due to cost and complexity including load cells, image processing, active infrared, and laser scanners.

A mature technology for detecting people is passive infrared. It is popular for motion detection triggered lights and security systems and is thus mass produced, well tested, and inexpensive. The IVLAB acquired a passive infrared sensor and mounted it to the front seat of our research vehicle (2009 Chevrolet Impala) (see Picture 3). The sensor was aimed forward towards the passenger's feet/legs. The sensor performed well and detected even slight motion of the passenger's feet/legs. It also proved insensitive to the heating system and vibration. More testing on various vehicle/seat types is needed, but the sensor shows promise as a passenger presence detection sensor. It can be mounted under the front seats aiming backwards to detect rear passenger feet in a similar manner. It should be noted that it is possible for a passenger to not be detected if the passenger remains very still for the duration of the drive. The likelihood of teenage passengers remaining very still for a significant period of time is small.

One issue that needs consideration is mounting of equipment. Various makes/model of vehicles have different seat designs. This makes designing a universal mount non-trivial. Tests in the Impala showed that a sensor worked when the bracket holding the sensor was adhered to the vehicle floor underneath the seat using double sided tape. The sensor was oriented towards the front passenger and then towards the rear passenger. The sensor was able to detect passenger movement in both orientations. Again, more testing in different vehicles is required, but if the sensor can be mounted to the floor it would make mounting the sensor practical.



Picture 3: Passive infrared sensor mounted near the bottom of the passenger seat in a 2009 Chevrolet Impala.

2.4. Speed Monitoring and Feedback Subsystem

The SMFS will inform a teen driver about the current posted speed limit, monitor compliance with the speed limit, and provide feedback to a teen if they are speeding. In order to provide the SMFS functionality, the speed and position of the vehicle must be known and a database with speed limit information must be queried.

The IVLAB has extensive experience using GPS to locate vehicles. GPS receivers come in varying cost/accuracy levels. For this application, a single phase GPS receiver capable of receiving Wide Area Augmentation System (WAAS) corrections will suffice. The IVLAB has experience with the Garmin 18x receiver (Picture 4). The receiver has an accuracy of less than 15 m (95% typical) in standard position mode, but also processes WAAS corrections improving the accuracy to less than 3 m (95% typical). The sensor has proven to be reliable and should fulfill the positioning requirements of this subsystem.

Picture 4: The Garmin 18x OEM receiver

To measure speed, GPS can be used. However, the speed measured by GPS will be the true vehicle speed, not the speed shown in the speedometer. The speed shown in the speedometer is usually biased upwards so that drivers are not going faster than shown. This speed can be obtained from the vehicle's On Board Diagnostics (OBD-II) port. To obtain the vehicle's speed, the Safer Teen Car FOT will use an OBD-II to Bluetooth converter/transceiver. The data on the OBD-II bus will be read using a Bluetooth wireless communications link to the converter eliminating the need to run a data cable.

The Safer Teen Car FOT is naturalistic because participants are allowed to drive anywhere they normally would. This means that a comprehensive map covering a large area in the DC and Twin Cities metropolitan areas is needed. Given the budget and resource constraints of the project, it is not practical for us to create the speed limit map, although we have significant experience and technical expertise to do so. Thus, a third party map was acquired from NAVTEQ Corporation. The map database will be installed on an SD card in the main processing unit. Software written by the IVLAB will query the database to determine the speed limit at the position provided by GPS.

The database contains five function classes of roads. Function classes one through four have speed limit data. Function class five does not contain speed limit data. Here is the definition of each function class.

- Functional Class = 1 roads allow for high volume, maximum speed traffic movement between and through major metropolitan areas. Functional Class = 1 is applied to roads with very few, if any, speed changes. Access to the road is usually limited to interchanges.

- Functional Class = 2 roads are used to channel traffic to Functional Class 1 roads for travel between and through cities in the shortest amount of time. Functional Class = 2 is applied to roads with very few, if any speed changes that allow for high-volume, high-speed traffic movement.

- Functional Class = 3 is applied to roads that interconnect Functional Class = 2 roads and provide a high volume of traffic movement at a lower level of mobility than Functional Class = 2 roads.

• Functional Class = 4 is applied to roads that provide for a high volume of traffic movement at moderate speeds between neighborhoods. These roads connect with higher functional class roads to collect and distribute traffic between neighborhoods.

• Functional Class = 5 is applied to roads whose volume and traffic movement are below the level of any functional class. In addition, walkways, truck only roads, bus only roads, and emergency vehicle only roads receive Functional Class = 5. The following also receive Functional Class = 5:

♦ Access roads, parking lanes, and connections internal to the complex of select POIs in the United States.

For the Twin Cities Metro area, the percentage of road miles that have speed limits for each function class is shown in Table 16. The map covers over 80 percent of the road length in the Twin Cities for Function Class 1 through 4 road segments. The road coverage percentages are reduced by an area south of the Twin Cities in Dakota County (Figure 11). NAVTEQ has not yet mapped this area for speed limits, but is scheduled to do so this year. The Minnesota FOT is likely to take place in Washington County. The speed limit coverage in this county is similar to the speed limit coverage in the state (Table 17).

Table 14: The Twin Cities NAVTEQ map speed limit coverage

Function Class	Total Length of Road Segments (km)	Length of Road Segments With Speed Limits (km)	Percentage of Road Segment Length With Speed Limits
1	609.11	581.04	95.4
2	945.52	939.41	99.4
3	1,699.76	1,376.32	80.9
4	5,173.3	4,460.93	86.2
5	23,498.94	0	0

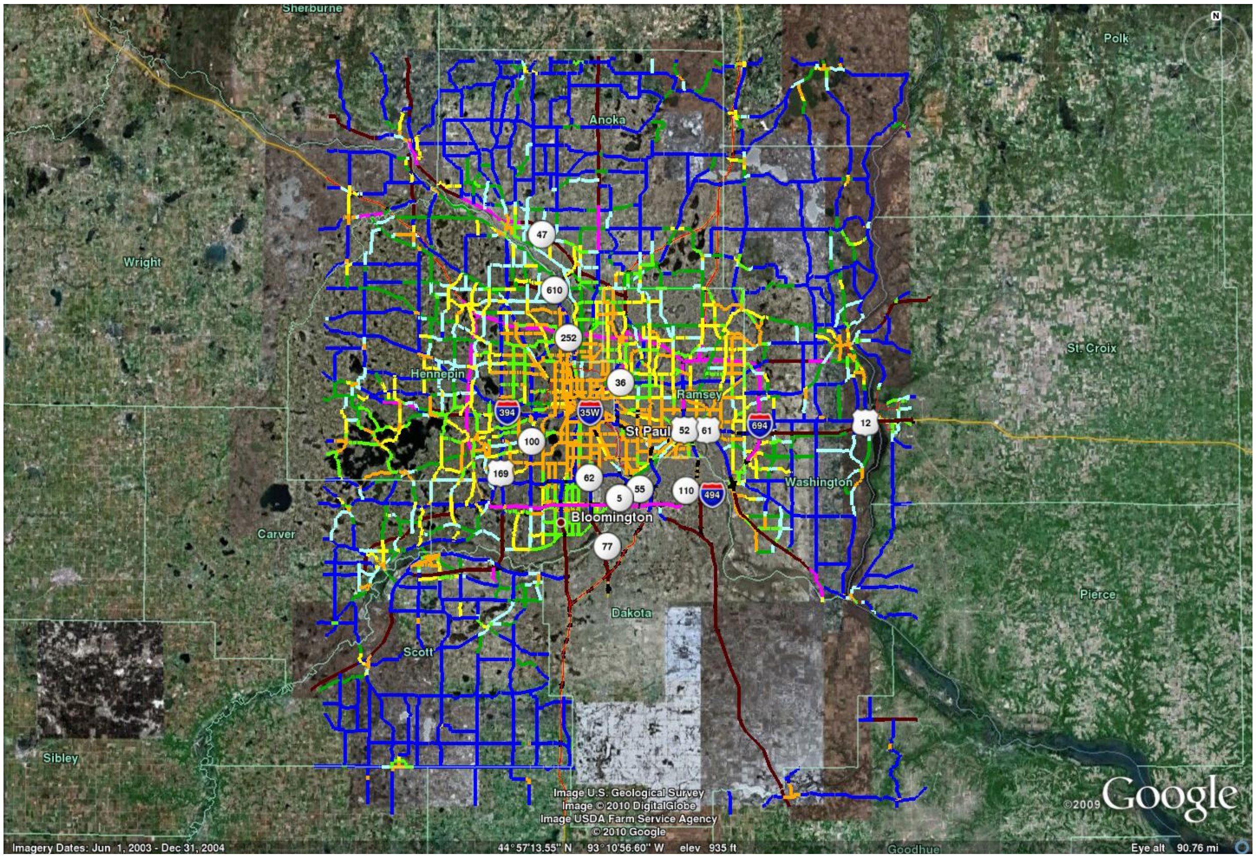


Figure 7: Roads of function class 1 - 4 with valid speed limits in the Twin Cities Metro. Red = 70 mph, maroon = 65, magenta = 60, blue is 55 mph, green = 50, cyan = 45, yellow = 40, light green = 35, and orange = 30.

Table 15: NAVTEQ map speed limit coverage for a section of Washington County, MN in Minnesota

Function Class	Total Length of Road Segments (km)	Length of Road Segments with Speed Limits (km)	Percentage of Road Segment Length with Speed Limits
1	115.69	103.33	89.3
2	100.13	94.38	94.3
3	212.50	169.36	79.7
4	733.69	639.89	87.2
5	3,049.34	0	0

The speed limit coverage for the Metropolitan District of Columbia map is shown in Table 18 and Figure 12 for example purposes only. The map covers over 89 percent of the road length for Function Class 1 through 4 road segments. Most of the roads without speed limit information were in Carroll County. NAVTEQ has not yet completely mapped that county for speed limits but plans to do so in late 2010. The Maryland FOT will likely take place in Montgomery County. The speed limit coverage in the included section of Montgomery County is similar to the speed limit coverage in the whole District of Columbia map.

Table 16: The District of Columbia NAVTEQ map speed limit coverage

Function Class	Total Length of Road Segments (km)	Length of Road Segments with Speed Limits (km)	Percentage of Road Segment Length with Speed Limits
1	13,901.83	13,901.83	100
2	21,622.57	21,592.05	99.9
3	35,075.42	34,471.40	98.3
4	88,807.01	79,503.97	89.5
5	45,6410.80	0	0

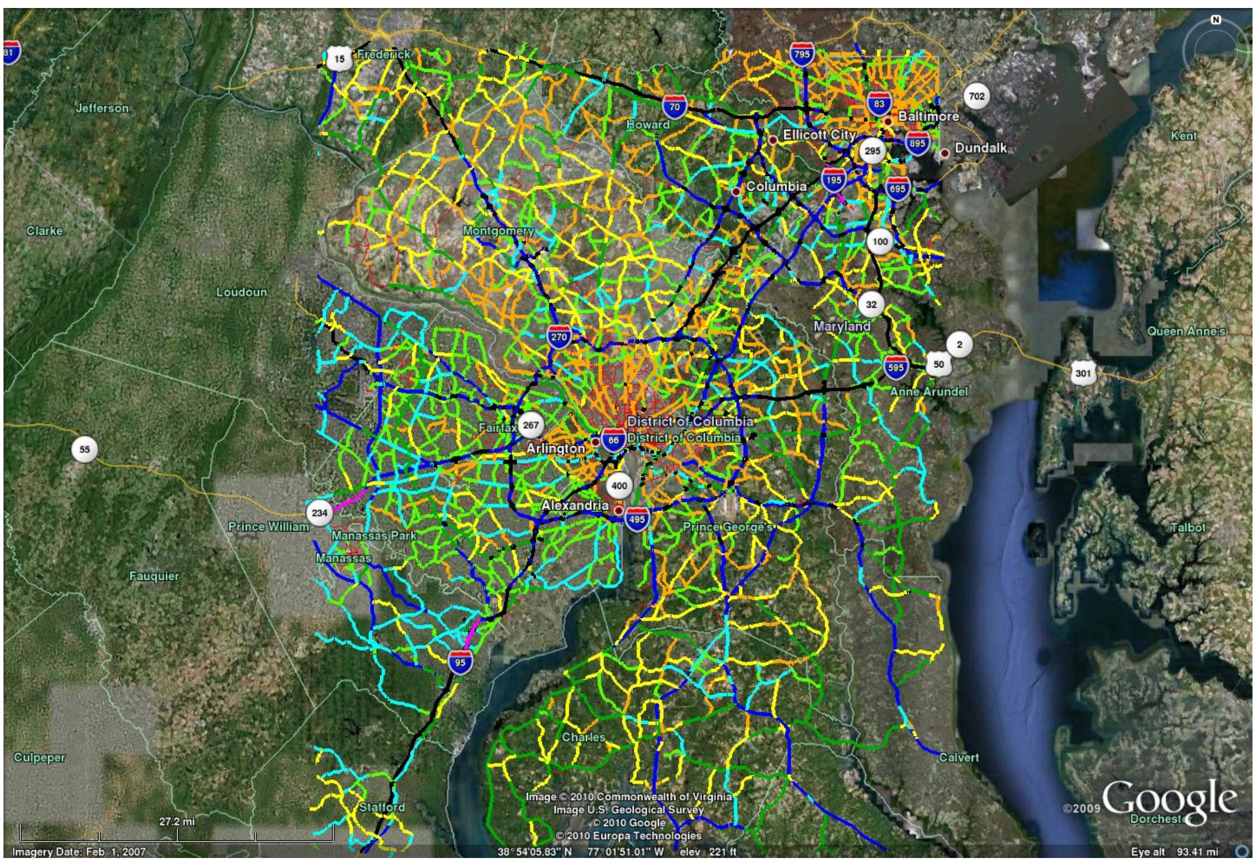


Figure 8: Speed limit coverage for a portion of Montgomery county in Maryland. Red = 70 mph, maroon = 65, magenta = 60, blue is 55 mph, green = 50, cyan = 45, yellow = 40, light green = 35, and orange = 30.

Table 17: Montgomery County, Maryland NAVTEQ map speed limit coverage

Function Class	Total Length of Road Segments (km)	Length of Road Segments with Speed Limits (km)	Percentage of Road Segment Length with Speed Limits
1	828.58	828.58	100
2	1,141.80	1,141.80	100
3	2,443.83	2,244.30	91.8
4	7,146.34	6,685.44	93.6
5	2,922.75	0	0

The road database is sufficient to provide speed limit information on a majority of roadways. The Function Class 5 roads that do not have speed limits tend to be low volume neighborhood roads that have statutory speed limits. On these roads, an assumed statutory speed limit can be employed. The NAVTEQ map does provide a speed range for function class five roads. An alternative to assuming the statutory speed limit on Function Class 5 roads is to provide a suggested speed based upon the speed range on the current segment of road. These alternatives will be investigated by comparing the NAVTEQ map to a MN/DOT-provided map of Washington County. A cross reference analysis will provide insight into the effectiveness of both strategies.

2.5. Excessive Maneuver and Feedback Subsystem

This subsystem will monitor lateral and longitudinal forces in the vehicle using an accelerometer and provide feedback to a driver if those forces exceed predetermined thresholds. To measure acceleration, a small inexpensive accelerometer from analog devices (ADXL345) will be used. It measures acceleration in three axes, is low power, and has 10-bit resolution. The accelerometer will be installed inside the dash-board in an orientation to be determined. Thus, a calibration procedure will be required to determine its transformation to the vehicle coordinate system. Once calibrated, the accelerometer can be used to trigger feedback for excessive maneuvers. The IVLAB has acquired the ADXL345 and preliminary testing in the lab's research vehicle has shown that this sensor has promise to deliver the functional requirements of this subsystem.

2.6. Cell Phone Use Detection and Mitigation Subsystem

The goals of the CDMS are to reduce the probability that drivers will use their cell phones and to mitigate the effects of cell phone use on crash risk. To accomplish this, the Safer Teen Car FOT system must be able to detect cell phone use. This can be accomplished by a radio frequency scanner that is tuned to listen to the frequencies associated with cell phone calls. Note, it is not possible using this technology to effectively detect sending or receiving text messages. This is due to the fact that no radio signals are given out while a text message is being composed. Only when the user presses the send button is the message sent. A very brief radio frequency signal is sent at this time that is difficult to distinguish from noise.

Four cell phone detectors of various price points were acquired to determine how well they detect cell phone use from various cell phones in a vehicle. The CELLBUSTER detector CB610 (Picture 5) detects RF signals with frequencies ranging from 400-2000MHz. The SureSafe SH-055SRV RF signal detector detects RF signals with frequencies ranging from 50-6000MHz (Picture 6). The P3 International P7030 wireless camera and cell phone detector (Picture 7) detects RF signals with frequencies ranging from 50-3000MHz. Finally, the Vibrating Pocket Detector VPD-10 (Picture 8) detects RF signals with frequencies ranging from 200-1000MHz.

Picture 5: The CELLBUSTER cell phone detector (CB610)

Picture 6: The SureSafe SH-055SRV RF signal detector

Picture 7: P3 International P7030 wireless camera and cell phone detector

Picture 8: Vibrating Pocket Detector VPD-10

The devices were first tested in the lab with various cell phones to determine if they had potential for CDMS. Lab testing revealed that the P3 international P7030 and the VPD-10 performed poorly in detecting cell phone use. Thus, they were eliminated from further consideration. The CELLBUSTER and the SureSafe SH-055SRV signal detectors did detect cell phones in the lab and were further tested in a vehicle. The two RF detectors were tested in a 2009 Chevrolet Impala while driving in the Twin Cities Metro area. Three cell phones were used to make and receive phones calls; the Google G1 (AT&T GSM network), Google Nexus One (T-mobile 3G network), and the Apple iPhone (AT&T 3G network). The results follow.

(1) CELLBUSTER ($795) [sensitivity was set to about 50%]
-- Google G1 (AT&T GSM network) --> made 20 calls, detected all 20 calls, 4 false alarms
-- Google Nexus One (T-mobile 3G network) --> made 20 calls, detected 1 call, failed on 19 calls
-- Apple iPhone (AT&T 3G network) --> made 10 calls, detected 2 calls, and failed on 8 calls

(2) SureSafe SH-055SRV RF Signal Detector ($58.95) [sensitivity was set to 5.5]
-- Google G1 (AT&T GSM network) --> made 20 calls, detected 14 calls, and failed on 6 calls, 4 false alarms
-- Google Nexus One (T-mobile 3G network) --> made 20 calls, failed to detected all 20 calls
-- Apple iPhone (AT&T 3G network) --> made 10 calls, and failed to detected all 10 calls

Neither detector performed well at detecting 3G phones (Nexus One, iPhone). The CELLBUSTER did a better job detecting GSM phones. However, it is large in size (20W x 11.2H x 5D cm) and over 13 times more costly than the less expensive SureSafe SH-055SRV RF signal detector. The CELLBUSTER performance did not justify the much higher cost and its size makes installation problematic. For these reasons, the SureSafe SH-055SRV RF signal detector was selected for the use in this subsystem. The detector provides a sensitivity dial that will need to be adjusted for every installation. The sensitivity will be calibrated to produce the best detection-to-false alarm ratio for a phone carried by the driver. Since the signal detector does not detect newer 3G technology, participants with GSM phones should be recruited.

2.7. Driving Context Subsystem

The driving context subsystem is intended to recognize the presence of external risk factors whose presence may be incorporated into the algorithms for driver feedback or vehicle adaptation. Contextual factors in this subsystem include weather conditions and time of day. The vehicle CAN bus contains information like wiper status and tire slip that make weather contextual warnings trivial. The vehicle OEMs do not provide this information on the OBD bus. Therefore, for the FOT only the light condition driving context will be considered. For this, GPS can be used to determine the time of day and location. A look up table with sunset/sunrise times for various locations and date/times will be used to determine if the teen is driving at night or during the day.

3. Safer Teen Car Vehicle Pack design

The technical and practical feasibility analysis contained herein demonstrates the likely implementation of the Safer Teen Car FOT. A proof of concept prototype was built and installed on a 2009 Chevrolet Impala. Initial results show promise that the proposed Safer Teen Car vehicle pack can provide all the functionality (and limitations) described in this document. However, the installation of the proposed system in one vehicle does not allow for an analysis of the variability of different vehicle makes and models. To address this, five prototype FOT vehicle packs will be built and installed in IVLAB and HumanFirst employee vehicles. The result of the prototype installation will further validate the technologies of the system that prove reliable but may necessitate the reconsideration of technologies that prove infeasible or unreliable in different vehicle configurations. In the unlikely case that one of the selected technologies proves infeasible or unreliable, alternative technologies will be investigated, but there are no guarantees that an alternative technology will meet all the requirements of the system or be included in the final design.

The safe teen car system must be easy to install and must not permanently alter the participant's vehicle. Also, since the STC vehicle pack will be installed in participant vehicles, it must be easy to uninstall without causing damage the participants' vehicles. With this in mind, the STC vehicle pack was designed to use wireless communication whenever feasible. It is also designed to be low power and compact so that it can be easily hidden for an "in factory" installation appearance. A system overview of the proposed vehicle pack is shown in Figure 13.

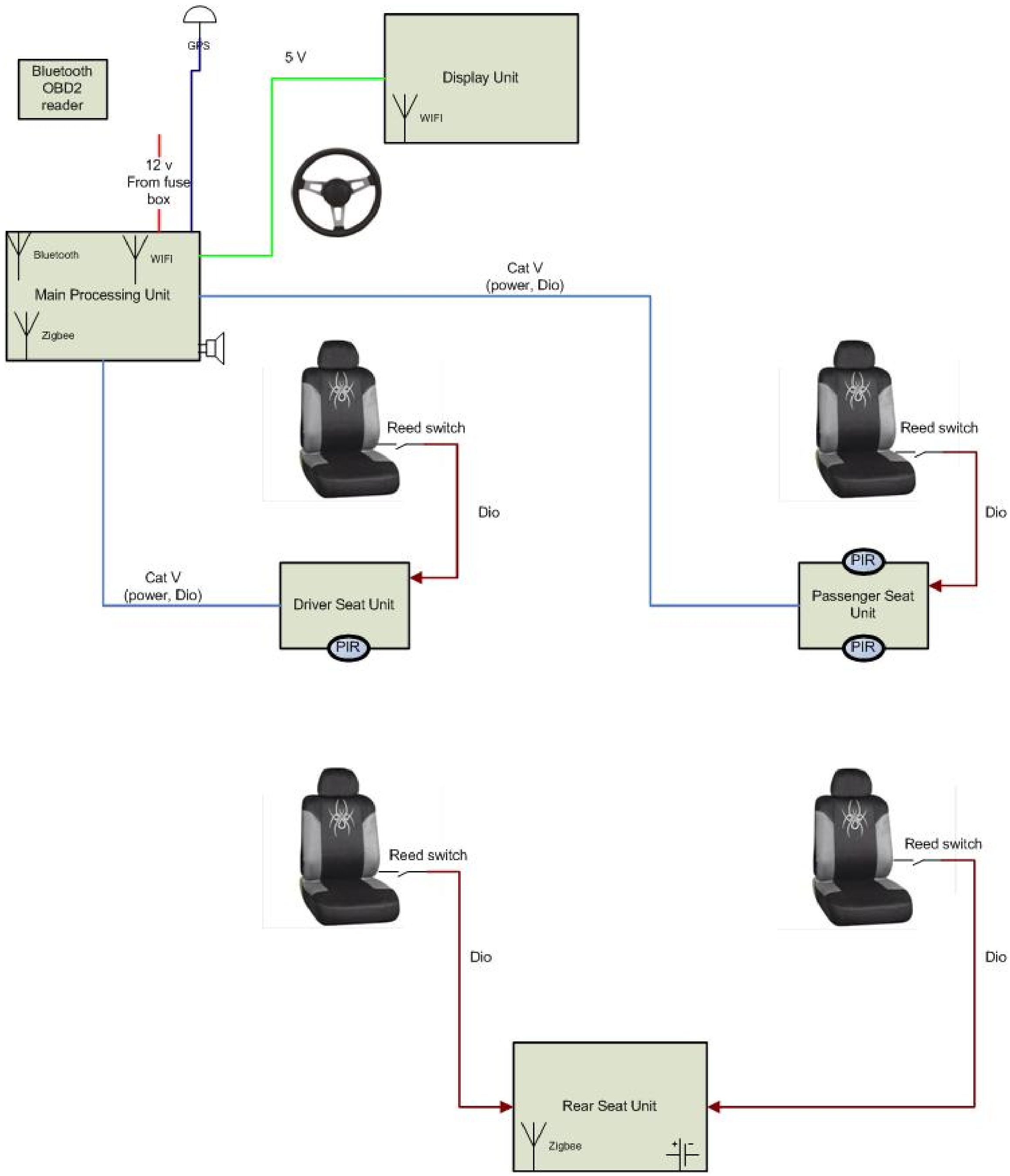


Figure 9: Safer Teen Car vehicle pack design

3.1. Main Processing Unit

The main processing unit is the heart of the system. It receives data from all the subcomponents of the system, determines the warning state, gives audio warnings and signals the display unit as to which visual warning to display. The unit consists of an ARM processor based computer with analog IO, digital IO, USB, serial, Wi-Fi, Bluetooth, Ethernet, and Zigbee communications. The main processing unit will also contain the RF detector and RFID tag reader. The unit is powered by the vehicle fuse box and provides power to the display unit, driver seat unit and the passenger seat unit.

The main processing unit obtains power from the fuse box located inside the cab. The installer will use an unswitched fuse when possible, allowing the main processing unit to remain powered even when the vehicle is turned off. The main processing unit monitors the vehicle's DC voltage to determine if the car is running. If it detects the car has been turned off (voltage drop), it enters a low power state by turning off all peripherals and wireless radios. This allows the STC system to "boot" up quickly after the vehicle has been started by simply waking up and turning on all peripherals and wireless radios. While all reasonable attempts will be made to reduce power consumption as much as possible, the vehicle will be required to be driven regularly to keep the battery charged. The vehicle will need to be driven every three days at a minimum. If an unswitched power source cannot be located, then the system will power down when the vehicle is turned off. While every reasonable attempt will be made to speed up the main processor boot sequence, there will be a delay between when the vehicle is turned on and the STC system is ready to provide interaction. For this reason, it is preferable to find a continuous power source.

The main processor unit will be mounted inside the dash-board near the fuse box at a location at the discretion of the installer. It should be mounted in a place that does not obstruct the driver and is hidden from view, if possible. The speaker may have to be mounted in sight based upon the acoustics of the cab. The audio warnings must be audible to the passenger.

Software written by the IVLAB will read information sent by all subsystem components. The logic of the warning sequence will be programmed (as described in the Task 1 report, Manser et al., 2010) and the audio warnings will be sent to a small speaker mounted in the cab. The output of the warning logic will be sent to the display unit via WiFi so that the visual warnings can be displayed by the display unit.

3.2. Display Unit

The display unit provides visual information to the driver. It consists of an ARM processor based computer that is connected to a 3.5" capacitive touch LCD. The display unit obtains power from a USB cable connected to the main processing unit. The USB cable also carries a digital IO line that informs the display unit whether the vehicle is running. This allows the display unit to go into a sleep mode in which power consumption is limited when the vehicle is not running.

The display unit is of similar size to navigation units that are readily available at electronic stores. Thus, standard inexpensive navigation device mounts will be adapted to mount the display unit. The five vehicle prototype test will determine if this mount type is reliable. One design issue that was considered is that the display unit may look like a navigation unit to the untrained eye. This may provide incentive for thieves to break into the FOT cars to steal what they perceive is a navigation unit. Thus, the display unit will be designed to be removable much like a navigation unit so that the participant can remove and hide or take the display unit with them to discourage thieves. This means that it is possible for the teen to forget to attach the display and not receive the visual STC feedback. The presence of the display unit will be detected by the main processing unit and can be recorded to track display use. It is recommended that display use be incorporated into the payment scheme to encourage display use.

Software written by the IVLAB will implement the visual information as detailed in the Task 1 report (Manser et al., 2010). The unit will get instructions regarding which visual warning to display from the main processing unit via WiFi communication.

3.3. Driver/Passenger Seat Unit

The purpose of the seat units is to detect seat belt usage of the front seats and the presence of passengers in three seats (front passenger, rear passenger side, rear driver side) with the driver seat assumed occupied. The driver seat unit contains one PIR sensor and a reed switch attached the driver's belt receptacle. The passenger seat unit contains two PIR sensors and a reed switch attached to the passenger's seat receptacle. The only difference between the two units is that the driver unit does not have a forward oriented PIR sensor.

The seat units will be small so that they can be located under the front seats. Candidate vehicles must have two inches of clearance underneath the seat to allow for the seat units. This means that vehicles with aftermarket amplifiers and other extra hardware mounted under the seat cannot be considered for the FOT. The seat units are easy to install and can be attached to the vehicle cab floor. Spacers may be needed to raise the seat unit so that the passenger presence sensors have a clear view of passengers' legs and/or feet.

The seat units are connected and powered to the main unit by Category 5 Ethernet cables. Standard (not crossover) Ethernet cables can be used to connect the seat units. These cables must be run from the main processor to each seat unit. All reasonable attempts to hide the cable should be taken, but it may be not possible to conceal the cables completely.

3.4. Rear Seat Unit

The rear seat unit detects seat belt use in the two rear seats. The unit does not use power from the vehicle, but is powered by an internally contained battery. The decision to self-power the rear seat unit makes installation simpler as a power cable does not have to be run from the main processing unit to the rear seats. A Zigbee wireless radio device will be used to transmit seat belt data to the main processor unit. This allows the rear seat unit to be tucked under the rear seat with no physical connection to the main processing unit.

To achieve the maximum 10-week FOT time period, the Zigbee radio will be duty cycled (wake/sleep) to increase battery life. Battery life calculators and IVLAB testing show that a duty cycle of less than one minute will provide sufficient battery life so that the unit will remain powered for the duration of the 10-week FOT. This means that the subsystem reports seat belt usage less than one time per minute. This means that a rear passenger could theoretically unbuckle their seat belt for a period of time up to the duty cycle without being detected. The final duty cycle will be determined by the results of the 5-vehicle prototype test and will likely be considerably less than one minute.

4. Conclusions

The Safer Teen Car FOT system described in the Task 1 report details the components of teen behavior that need to be monitored and the feedback that needs to be provided to the driver. In this document, a technology analysis was conducted to determine which technologies provide the cost, performance and reliability needed to carry out the STC FOT. A proof of concept prototype vehicle pack was developed, built and installed in a 2009 Chevrolet Impala. The proof of concept prototype shows promise in delivering all the functionality described herein. Five prototype FOT vehicle packs are being built and will be installed in the Minnesota team member's vehicles in April 2010 to further test the reliability of the system in different vehicle types. Successful testing of the vehicle pack subsystems will determine the final STC vehicle pack design that will be deployed in 15 vehicles in the Twin Cities Metropolitan area and in 15 vehicles in a Metropolitan District of Columbia area.

5. References

Lerner, N., Jenness, J., Singer, J., Klauer, S., Lee, S., Donath, M., Manser, M., & Ward, N. (2010, August). *An Exploration of Vehicle-Based Monitoring of Novice Teen Drivers: Final Report.* (Report No. DOT HS 811 333). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Human%20Factors/Reducing%20Unsafe%20Behaviors/%EF%BB%BFDOT%20HS%20811%20333.pdf

Manser, M., et al. (2010). An evaluation of a prototype Safer Teen Car: Specify Subsystem Functions and their Performance Requirements (Task Order 1 Report). NHTSA DTNH22-08-D-00115, Task Order 2. Unpublished NHTSA report.

Appendix I

Evaluation of a Prototype Safer Teen Car: Conduct Evaluations of Subsystems

Task 4 Interim Report

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Table of Contents

1. Background and Objective

The Safer Teen Car project is a series of tasks that were set up to develop a technology solution for addressing teen driver risk factors. The focus is specifically on vehicle-based feedback and adaptation strategies, as opposed to approaches that record, transmit, summarize, and report on driver performance. The intent is to devise a model system that is effective in improving teen driver behavior and is also appealing to parents, acceptable to teens, and does not engender unanticipated and undesirable behaviors. Task 4: Conduct Evaluation of Subsystems is covered in this report. The overall project plan includes the following eight tasks:

- Task 1: Specify Subsystem Functions and their Performance Requirements;
- Task 2: Determine Enabling Technologies That Meet the Functional and Interface Specifications;
- Task 3: Develop and Review Data Collection and Analysis Plan;
- *Task 4: Conduct Evaluation of Subsystems*;
- Task 5: Build and Demonstrate to NHTSA the Prototype Car;
- Task 6: Conduct Stakeholder Outreach and Prototype Vehicle Evaluations, Develop Parent/Teen Information Program;
- Task 7: Document Final Specifications; and
- Task 8: Generate Final Report, Conduct Stakeholder Meetings.

The objective of Task 4 is to provide a preliminary assessment of the individual driver feedback subsystems that are envisioned as parts of the complete STC system. Observations of driver behavior and system acceptance from these assessments will be used to refine the systems and methods prior to the full system evaluation that will take place in Task 6. A full account of the Task 4 evaluation methods can be found in the Task 3 report titled, "An evaluation of a prototype Safer Teen Car: Develop and review data collection and analysis plan" (Manser, Graving, Rakauskas, Lerner, Jenness & Huey, 2010).

1.1. Overview

Motor vehicle crashes have been reported as a leading cause of death for 15- to 20-year-olds (Compton & Ellison-Potter, 2008). In 2009, teens 13 to 19 accounted for 3,466 deaths in motor vehicle crashes, which represented 12.3 percent of the passenger vehicle deaths overall (Insurance Institute for Highway Safety, 2008). The Center for Disease Control (2011) noted that 16- to 19-year-olds are four times more likely to crash a motor vehicle compared to older drivers. The crash rate for teen drivers is higher in the first six months of licensure, where teens lack driving experience and exposure, but continue to engage in risk-taking behaviors (Lee, Simons-Morton, Klauer, Ouimet, & Dingus, 2011; Mayhew, Simpson, & Pak, 2003). The efforts to reduce teen crashes have resulted in changes to licensing legislation and the creation of novel driver support technology.

In an effort to reduce fatal and non-fatal teenage crashes, graduated driver licensing (GDL) programs have been initiated in all States. GDL programs generally initiate passenger restrictions and reduce nighttime driving exposure in an effort to minimize teen driving risk (Williams & Shults, 2010). The resulting trends of the GDL programs show a reduction in the teen crash rate. However, GDL requirements rely heavily on parental involvement and teen compliance (Brookland & Begg, 2011). The investigation and use of supplemental technologies that aid teen drivers can help teens gain experience while abiding by traffic laws (Farmer, Kirley, & McCartt, 2010).

This project represents an effort to create and test a model for vehicle-based technology to address teen driver risk factors associated with teen driver crashes. Vehicle manufacturers could use the model within their product lines to build teen driver support systems. The University of Minnesota and Westat have developed a prototype driver support system called Safer Teen Car. The system provides feedback to drivers when risky driving behaviors are detected. The components of the system are outlined within the methods section of this report and detailed in previous project task reports (see Gorjestani, Menon, Arpin, Cheng, Huey, Lerner & Jenness, 2010; Manser, Graving, Rakauskas, Creaser, Lerner, Jenness, & Huey, 2010). A prescriptive model of driving behavior was considered when the features of the STC were designed. The aim was to generate a system that would result in a reduction of risky driving behaviors associated with known teen driver crash risks if a teen driver followed feedback delivered by the STC. These risky behaviors were captured in a Report to Congress (Compton & Ellison-Potter, 2008) that summarized the teen crash research and showed that teen drivers displayed a higher propensity for risk-taking due to immaturity and inexperience, were less likely to use seat belts, were more likely to speed or drive too fast for conditions, and were more likely to engage in in-vehicle secondary tasks (e.g., cell phone use, texting) while driving. Other factors shown to increase teen crash risk include driving at night, driving with teen passengers, and driving under the influence of alcohol. The subsystems within in the STC were designed to address the most common risk factors associated with teen crashes, such as seat belt use, speeding, distractions due to in-vehicle secondary tasks, and passenger presence.

This report presents the results of an evaluation that examined the extent teens and parents accepted and valued STC subsystems and how effective STC subsystems were at influencing driver behavior. The purpose of Task 4 evaluation was to obtain insight into what components of the prototype STC can be combined to create a holistic feedback and vehicle adaptation system for novice teen drivers. The evaluation also provided insight on effective design elements and supplementary subsystems for creating an acceptable and effective STC. Four major subsystems were evaluated; Excessive Maneuver, Speed Management, Cell Phone, and Seat Belt. As per the names of the subsystems, it was hypothesized that cell phone usage, excessive maneuvers, and speeding would decrease and seat belt use would increase (or would be maintained at a high level) for the participants of this evaluation who drove with the respective subsystems in their vehicle. There were adaptive qualities present within the Excessive Maneuver and Speed Management subsystems. The driving context, including the posted speed limit, time of day, passenger presence, and seat belt usage influenced thresholds for speed and excessive maneuver feedback. Adaptive features were not present for the Cell Phone subsystem as cell phone feedback was not reliant on contextual input from peripheral sensors and subsystems. This evaluation represents a preliminary functional on-road test of the STC system. The results of the evaluation will be used to refine the functionality of the system prior to an evaluation of the full STC. It should be noted that it was beyond the scope of this evaluation to explore the extent each STC subsystem influenced drivers to select *safe* driver behaviors that endured after the system was deactivated. A subsequent full-system field evaluation will explore this carryover effect.

1.2. Study Summary

To measure the extent the STC changed teen driver behavior, the evaluation included two specific stages for each of the participants. To begin, there was a two-week baseline stage in which the STC did not provide feedback to teens or adapt vehicle functions. The baseline stage was then followed by a two-week Treatment stage during which time the STC subsystems were activated and it provided feedback and vehicle adaptations to teen drivers. Driving behavior data was collected throughout the study and allowed for comparisons between the stages that would identify the extent to which the STC contributed to changes in driver behavior. At the end of the study each teen driver, accompanied by one parent, participated in unstructured discussions intended to understand their specific experiences and impressions of the STC subsystems to which they were exposed. Specifically, this activity provided insight into teen and parent experiences as well as insight regarding STC components they felt could be redesigned.

2. Methods

2.1. Participants

Twenty-eight (15 male and 13 female) teens participated in this study. In Minnesota, participants were recruited by flyers posted in community centers, at several high schools, and on Craigslist.com (see Appendix C). In Maryland, Westat staff recruited participants via Facebook.com, Craigslist.com, and Westat's Web site. At both locations an email was sent to groups of people who had asked previously to be contacted for driving studies.

For a teen to be eligible to participate as per the University of Minnesota Institutional Review Board requirements (Appendix D), a parent or guardian was required to be present when the STC was installed. Parents were required to sign a consent form (see Appendix A) and to be present for a review of the STC features. Teens were required to sign an assent form (see Appendix B) and to be present for the installation and review of the STC. Teens were required to have a minimum of six months of driving experience. Because of the very steep changes in driver performance and crash rates that occur during the first six months of licensure (e.g., Mayhew et al., 2003) this requirement provided a more stable basis for assessing subsystem effects.

To identify potential differences due to geographic location, teens were recruited from both the suburban/rural areas of Minneapolis/St. Paul metropolitan area (i.e., Washington, Hennepin, Anoka, and Scott counties) and also areas of Maryland (i.e., Montgomery County) bordering Washington, DC. The GDL requirements are different between Minnesota and Maryland. In Minnesota the nighttime driving restrictions are removed after 6 months of provisional licensure (e.g., 16.5 years old). Passenger restrictions are also relaxed after six months of "clean" driving such that teen drivers are allowed up to 3 passengers in the vehicle under age 20 (IIHS, 2011). Conversely, GDL requirements in Maryland mandate that teens are to be 16.5 years old before obtaining a provisional license. Additional limitations for Maryland teens include passenger restrictions such that no passengers younger than 18 are allowed for the first five months of provisional licensure. The nighttime restrictions are longer than those of Minnesota such that Maryland teens are restricted from driving between midnight and 5 a.m. until at least 18 years old (IIHS, 2011). The restrictions for both states can be imposed for longer terms and are dependent on teen compliance with the provisional licensure requirements.

As shown in Table 20, the mean age of teen drivers was similar between males and females and between testing locations. Average licensure duration was slightly higher for females and higher for Maryland teens. At the time of this study the minimum age of licensure was 16.5 in Maryland and 16 in Minnesota, which explains the variability in age. Three of the Minnesota teens had been licensed for an average of 6.7 months with 8 teens having been licensed for an average of 9.5 months. Only one Minnesota teen was fully licensed with no restrictions. Conversely, 7 Maryland teens had their provisional licenses an average of 7.2 months since licensure (e.g., 16.5 years) and 8 teens had their licenses an average of 16.1 months with no teens fully licensed and all teens restricted from night (e.g., midnight – 5 a.m.) driving. Males reported higher estimated weekly mileage compared to females, but rural teens reported higher estimated weekly mileage compared to their counterparts (see Table 20). For the Urban group, 11 participants drove passenger cars and 4 drove sport utility vehicles (SUVs). A total of 10 participants indicated they drove every day while 5 indicated they drove five or six days per week. For the rural group, 11 participants drove passenger vehicles and 1 participant drove an SUV. Nine participants estimated that they regularly drove every day, 2 estimated that they drove five to six days a week, and 1 estimated three or five days a week. One participant from the rural group was excluded from the study due to an equipment failure that occurred during STC installation.

Table 18. Teen Driver Age, Licensure duration, and Estimated Weekly Mileage

	Male		Female		Urban		Rural	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	17.6	0.4	17.7	0.3	17.8	0.3	17.4	0.4
Licensure Duration in Months	10.3	4.8	12.1	5.8	12.1	6.1	9.7	3.6
Miles per Week	123.0	83.7	91.8	43.4	94.3	54.1	127.9	84.1

2.2. Study Design

The complete STC system is envisioned as having four subsystems that provide direct feedback to the driver when an unsafe act occurs. These subsystems monitor seat belt usage, speeding, excessive maneuvers, and cell phone use. In the current experiment the seat belt subsystem was in effect for all participants. However, each participant received feedback from only one of the other three systems. In addition, the adaptive features that triggered the warnings were in effect and these thresholds were manipulated based on contextual factors (e.g., passengers, night) or the occurrence of other risky behaviors. Each subsystem group was analyzed separately.

As detailed in the Task 3 report (e.g., see Manser et al., 2010b), this preliminary functional road test required a total of 30 participants, with 5 participants assigned into each Subsystem Group at each testing location. Measures of driver performance were reported as averages per stage (i.e. all baseline data were aggregated separate from treatment data). Each dependent variable within each group was analyzed using a 2-by-2 mixed ANOVA with geographic location (Rural-MN, Urban-MD) treated as a between-subject variable and stage (baseline, treatment) treated as a within-subject variable. Differences between means were considered significant at or below an alpha of <0.05. A Bonferroni alpha correction was used for all post hoc tests.

2.3. Apparatus

The STC contained an ARM processor-based computer that consisted of an analog IO, digital IO, USB, serial, WiFi, Bluetooth, Ethernet, and Zigbee communications. The computer was connected to the subcomponents of the system and it was programmed to interdependently activate and control the STC subsystems. The following provides a brief summary of the STC subsystems (a full description of the subsystems can be found in Manser et al., 2010 while a full description of their components can be found in Gorgestani et al., 2010).

- **Teen Driver Identification Subsystem (Identification Subsystem) -** The Identification Subsystem contained a RFID reader. At the beginning of the study each parent (or sibling who used the vehicle) was provided with a card that contained a passive RFID tag. The teen's parent was instructed to keep the card on their person throughout the study. If an RFID card was present in the vehicle (indicating a parent was present) a selection screen with buttons appeared that allowed parents to deactivate the STC.
- **Passenger Presence Subsystem (Passenger Subsystem)** - Three PIR sensors were placed in each vehicle to detect the presence of passengers in the front or rear passenger seats. One PIR was placed beneath the driver seat facing the rear driver-side seat, one beneath the front passenger seat facing forward, and one beneath the front passenger seat facing rearwards. These three passenger seat positions were selected to keep passenger detection processes consistent between vehicle types. In practice, PIR sensors are often used to detect motion, however, in this case the PIR sensors were implemented to record vehicle occupancy by detecting the heat signature of passenger leg motion.
- **Seat Belt Detection Subsystem (Seat Belt Subsystem)** - Reed switch magnets were attached to the seat belt buckle and tongue for the four seat positions. A closed reed switch (i.e., when the magnets were in close proximity) indicated the seat belt was fastened. A *warning* that paired an auditory voice component with a visual icon displayed on the driver-vehicle interface was presented when an occupant's seat belt was not fastened. There were two types of audible warnings for the driver seat position. A *reminder phase* ("Buckle seat belt.") that occurred if the driver buckle was not fastened when the car was stationary and a *motivator phase* ("Driver, buckle seat belt.") that cycled every 30 seconds if the driver remained unbuckled while the car was in motion. The two audible warnings were paired with a visual icon and text stating "Driver, buckle seat belt." There was a unique audible for the front passenger, driver-side rear passenger, and passenger-side rear passenger seat positions (e.g., "Driver-side rear passenger, buckle seat belt" for the passenger position in the rear behind the driver). The passenger warnings were accompanied by a visual icon and text stating, "Passenger buckle seat belt."
- **Driving Context Subsystem (Context Subsystem)** – Crash risk for teen drivers' increases during nighttime driving conditions and thus the STC feedback was provided to account for this known risk. A nighttime condition was determined by comparing time of day on the STC clock to known sunrise and sunset times. When the system identified a nighttime condition the Context subsystem reduced thresholds for both the Maneuver and Speed Subsystems.
- **Cell Phone Use Detection and Mitigation Subsystem (Cell Phone Subsystem)** – To detect cell phone use within a participant's vehicle an RF detector was installed. The RF detector was tuned to detect simple Global Systems for Mobile communication (GSM) and Code Division Multiple Access (CDMA) cell phone RF ranges. Complex cell phones that are

often programmed to send data continuously, like "smartphones," would have caused the feedback from the Cell Phone subsystem to occur regardless of the type of use. Therefore participants with smartphones were excluded from the current study. When a cell phone call was detected a warning was presented that consisted of a one-second beep, followed by the phrase "Cell phone detected" then a second one-second beep. The cell phone subsystem did not distinguish between driver and passenger cell phones.

- **Excessive Maneuver and Feedback Subsystem (Maneuver Subsystem)** –The maneuver subsystem provided feedback to drivers when a vehicle maneuver (i.e., lateral and longitudinal acceleration) exceeded a critical threshold. The unmodified threshold was .5g (~4.9m/s^2, which is equal to a change in velocity equal to approximately 11 mph in one second). The threshold value was modified by the status of the Context Subsystem, Passenger Subsystem, Seat Belt Subsystem, and the speed limit of the roadway traveled. For example, the amount of acceleration that triggered an excessive maneuver warning decreased at night, if there were three passengers present, or if the driver or a passenger were not buckled. The threshold also changed in a negative linear fashion with the speed limit (i.e. at greater speeds the threshold decreased). The input from the subsystems was additive, such that when the subsystems detected co-occurring events the threshold was further reduced. The maneuver warning consisted of a visual icon synchronized with a 10-second tone.
- **Speed Monitoring & Feedback Subsystem (Speed Subsystem)** –The Speed Subsystem provided feedback to drivers when the vehicle speed was greater than a set of criteria. If participants exceeded the speed limit by 2 mph a mild speed warning was presented. The mild speed warning consisted of a 1-second auditory tone. If participants increased their speeds and drove 2 mph to 15 mph above the speed limit a second strong speed warning was presented. The strong speed warning included the phrase "Speeding violation" followed by a 1-second buzz. During the strong speed warning a visual icon (i.e., speed limit sign) changed from white to red on the DVI. The speed subsystem threshold for the strong warning was modified by the status of the Seat Belt Subsystem, the Context subsystem, and the speed limit of the roadway. The input from the other subsystems were additive. When the subsystems detected co-occurring events the threshold was further reduced.

2.4. Procedures

When participants arrived at the research facility (University of Minnesota or Westat) they were greeted and escorted to a meeting room. Parents and teens were then asked to complete consent and assent forms, respectively, prior to participating in the study. Upon parental consent and teen assent the teen vehicle was then taken to an installation bay for STC installation. The installation process took approximately three hours. Participants were randomly assigned into the subsystem groups that consisted of participants who drove with the Speed Management subsystem (Group 1), the Excessive Maneuver subsystem (Group 2), or the Cell Phone subsystem (Group 3). The Teen Driver Identification, Seat Belt, Passenger Presence, and Driving Context subsystems were provided to all participants in each of the three groups. Note that passenger presence and context did not influence feedback from the Cell Phone subsystem. During the installation period teens and parents reviewed the assigned STC subsystem functionality. The format of the review included a PowerPoint presentation of each subsystem and their related functionality. Each presentation was tailored to the specific subsystems being installed on the participant vehicles. The review included pictures of the subsystem and visible components within the vehicle. The auditory and visual feedback associated with some of the subsystems was given or shown so that participants could understand what their subsystem would display. In addition, a brief overview was given with respect to the interaction of the different threshold levels for the subsystems. The review for each participant lasted approximately 45 minutes and experimenters answered questions as they arose. After a successful STC installation teens and parents were then released and the baseline stage of the study began.

Participants met with the research team three times after the initial STC installation. The first meeting occurred within five days of STC installation and was conducted to verify system functionality and data validity and to troubleshoot any initial issues encountered by participants. The second meeting occurred two weeks after STC installation and was conducted to initiate the two-week Treatment phase by activating the STC feedback and vehicle adaptation functions. The final meeting was to conclude the study. During the final meeting the research team members uninstalled the STC system from the teen vehicle and then debriefed and collected unstructured discussion information from teens and their parents about their STC experiences and potential issues. These discussions allowed participants to highlight different experiences with the system and also gather parental input about the system and its use. Teens received $200 and parents received $50 as incentive for their participation.

2.5. Analysis

There were two types of data obtained from this study. The first was objective vehicle and driver data collected using the measurement equipment within the STC. The second type was usability data that was collected using unstructured discussions. The following section summarizes each of the data measures.

2.5.1. Vehicle and Driver Data

The following data were collected directly from the STC:

- Latitude and longitude coordinates of vehicle position;
- Distance driven (miles);
- Posted speed limit (mph);
- Vehicle speed (kph);
- X, Y and Z acceleration (m/s^2);
- Occupancy (the driver and up to 3 passengers);
- RFID;
- Seat belt activation;
- Time of day;
- Count of system warnings.

The following measures were derived from the STC data identified above.

- Seat Belt Detection Frequency (SBDF) – The percentage of miles driven while the seat belt was fastened for each seating position.
- Passenger Presence Detection (PPD) – The percent of miles driven when the PIR sensors were triggered. Each seat position was reported separately.
- Feedback Rate (FR) – The frequency of the mild speed warning, the strong speed warning, the maneuver warning, the cell phone warning, and the seat belt warnings (for

all seating positions). The ratio of the occurrence of these warnings per mile driven was calculated.

- Speeding Miles (SM) - The percentage of miles driven at speeds greater than the posted speed limit was calculated. This measure was only available for road segments represented within the NAVTEQ database with a speed limit. Speed data for road segments with speed ranges were excluded as an accurate speed could not be derived.
- Speeding Exceedance (SE) – The percentage of miles the vehicle was driven at speeds greater than the speed limit but equal to or less than 5 mph greater than the speed limit; greater than 5 mph but equal to or less than 10 mph above the limit; greater than 10 mph but equal or less than 15 mph above the limit, and greater than 15 mph above the posted speed limit. The Speeding Miles measure was only available for road segments represented within the NAVTEQ database with a speed limit. Speed data for road segments without a precise speed limit were excluded from this measure.
- G-Force Threshold Exceedance (G) - Positive and negative lateral accelerations as well as positive and negative longitudinal accelerations were recorded. The percentages of miles driven within the four ranges of acceleration are reported. Non-directional acceleration is also reported. The ranges selected for analysis were between 2 m/s^2 and 3 m/s^2, between 3 m/s^2 and 4 m/s^2, between 4 m/s^2 and 5 m/s^2, and in excess of 5 m/s^2. For reference, 1g is equal to 9.82 m/s^2.
- System warning count - For the baseline condition a count was established to identify when the system would have issued a warning if the STC had been active. The count was then tallied and divided by the total miles traveled as a measure of the warning frequency per mile.

2.5.2. Usability Data

The results of a transport telemetric acceptance assessment (van der Laan, Heino, & de Waard, 1996) and usability assessments are reported. The acceptance results provide insight into the extent participants found the STC useful and satisfying. Summaries of the unstructured discussions are reported to provide a brief but comprehensive overview of the items discussed by parents and teens.

3. Results

The presence of RFID markers in the data indicated vehicle miles traveled when someone other than the teen participant was in the vehicle. In light of this, data containing RFID markers were excluded from all analyses. RFID markers were present for 21 percent of the total mileage (20% of the GPS mileage). The table in Appendix L illustrates how the presence of RFID makers varied by participant. There were several participants without RFID markers and several participants with a high percentage of mileage with markers. The cause of this differential result is not clear. A participant without RFID makers may have had system issues that caused the system to malfunction and not detect the RFID card throughout the study, participants with a high percentage of their miles driven with an RFID marker may have left the RFID card in the car rather than have their parent keep it on their person as per the instructions (e.g., 77% of the data from participant 315 had RFID markers). The decision to exclude these data was based on low selection rates for the adult mode when an RFID card (e.g., marker) was present. The presence of the RFID markers and the absence of adult mode selection did not provide enough information to discriminate if a teen was driving with an adult, an adult was driving in teen mode, or a teen was driving without an adult but the RFID card was still present.

The speed limit was known for 61 percent (8,457 miles) of the recorded miles driven by all participants (13,771 miles). The amount of miles travelled without a known speed limit was higher in Maryland (2,783 miles) than Minnesota (2,531 miles; see Appendix K for mileage). Occasional GPS signal loss, GPS signal but no map data (e.g., a void in the reference map), and speed ranges (e.g., no absolute speed limit is defined) affected the feedback provided by the Speed Management subsystem. Speed limit data was obtained based on comparisons between GPS location and the speed limit database. The comparison data was used as input for feedback provided by the Maneuver and Speeding subsystems and was used to calculate speed related dependent measures (e.g., Speeding Miles, Speeding Exceedance, and Feedback Rate). When speed limit data were not available (e.g., due to GPS signal loss, absence of NAVTEQ map coverage, or speed range) these data were not calculated and subsequently not included in the analyses. For both sites combined, feedback to participants who drove with the Speed Management subsystem was available for 59 percent of their total miles driven in the study, and for participants who drove with the Maneuver Subsystem the threshold adjustment that relied on speed were available for 63 percent of their total miles (see Appendix K). The functions of the Cell Phone Subsystem were not affected by the absence speed limit information.

The data were separated based on data collected when passengers were present (Driver and Passenger) and when no passengers were present (Driver only) because teens change their driving behavior when passengers are present. The Driver only and Driver and Passenger data were further separated based on the time of day (day or night) because driver behavior during daytime driving is different compared to driver behavior at night (e.g., crash rates are higher for night driving compared to day driving that is likely due to changes in visibility and driver behavior). The research team was aware of this possibility and in an effort to improve the safety of driving at night the STC was designed to account for such differences. The report by Manser et al., (2010a) provides thorough information with regard to the thresholds of the different subsystems, however the maneuver and speed feedback threshold reductions were programmed to occur at night using the GPS timestamp and a lookup table that contained the times for sunrise and sunset. This feature was reviewed with participants the first day of participation. In light of these considerations the data was organized into four sets for analysis that included Driver-Night, Driver-Day, Driver and Passenger-Night, and Driver and Passenger-Day. The amount of miles driven in daytime and miles driven at night are reported in Appendix N. Independent analyses were completed for each level of all dependent measures within each data set. Only significant differences are reported.

3.1. Excessive Maneuver Subsystem group

Overall, the results from the Excessive Maneuver subsystem did not show significant differences for the maneuver behavior between the baseline and treatment stages. The non-significant results may be attributable to a lack of effects, small sample size, or the reduced power of the statistical test. Results, averages, standard deviations and sample sizes for the Excessive Maneuver Subsystem group analyses are presented in Table 4-6. Significant differences were found on a few measures that are described in more detail below.

Speeding Exceedance

The Speeding Exceedance measures are reported as a percentage of total miles driven with GPS coverage (GPS miles). Accordingly, the GPS signal losses discussed earlier caused the exclusion of two participants from Maryland (322 had missing GPS information and 323 had no map data) from the analysis of the Speeding Exceedance measure. There was a significant main effect of Location for the speed range greater than 5mph to 10mph above the speed limit (5-10mph>SL) at night and for the speed range greater than 10mph to 15mph above the speed limit (>10-15mph>SL) both day and night. Both were significant when only the driver was present in the vehicle. Participants from Maryland drove within these ranges significantly more often compared to Minnesota participants.

Results indicated a significant main effect of Stage for drivers (only) during daytime conditions for the 10 mph to 15 mph above the speed limit range. In particular, participants had a higher percentage of the total miles in this range during the Treatment (e.g., Excessive Maneuver subsystem activated) when compared to baseline.

G-Force Threshold Exceedance

There was a significant effect of location while driving at night without passengers for the G-Force range of 2 to 3 m/s^2 negative acceleration (NegLon). The result suggests that participants from Maryland had a higher percentage of their total miles accelerating within this range compared to participants from Minnesota, but again, only at night. There was a significant effect of location while driving at night without passengers for the G-Force range of 3 to 4 m/s^2 negative acceleration (NegLon). The result suggests that participants from Maryland had a higher percentage of their total miles slowing down or braking within this range. Results showed a significant interaction between location and stage for day driving in the range of 4 to 5 m/s^2 (non-directional), but follow-up analyses to evaluate the mean differences in stage for both locations were not significant.

Seat Belt Detection Frequency

There was a significant main effect for stage during the day with passengers for driver seat belt compliance. This result indicates that there was a 13 percent increase in the percentage of total miles driven with driver seat belt compliance after the STC was activated.

3.2. Speed Management Subsystem

Overall, significant results were identified for a specific speed range for the Speed Management Subsystem group. Results showed a reduction in the amount of speeding miles between baseline and treatment conditions. The other speed groups were not significantly different that may be attributable to the lack of differences or reduced power because of a small sample size. Results, averages, standard deviations and sample sizes for the Speed Management Subsystem group analyses are presented in Table 22. In addition to data analysis issues, the primary results are summarized below.

G-Force Threshold Exceedance

There was a significant main effect for Stage for three of the G-Force Threshold Exceedance ranges. The results indicated a significant increase in the percentage of miles driven after the STC was activated for the ranges 3 to 4 m/s^2 (non-directional) for night driving and 4 to 5 m/s^2 (non-directional) for night driving. Results showed a significant interaction between Location and Stage for day driving in the range of 3 to 4 m/s^2 (non-directional), but follow-up analyses to evaluate the mean differences in stage for both locations were not significant.

Passenger Presence Detection

Participants from Maryland drove a significantly higher percentage of total miles during the day with a rear driver side passenger compared to participants from Minnesota. This result only applies to the Driver and Passenger data as this variable was not examined when it was only the driver in the car.

Table 19. Maneuver Subsystem group results. ***Note. *Follow-up tests were not significant.***

	Occupants	Time of day	Measure	*df*	*F*	*p-value*	MD	SD	n	MN	SD	n
Location	Driver	Night	5-10mph > SL	1,6	11.4	.015	18.5%	2%	3	8%	5.6%	5
	Driver	Night	10-15mph > SL	1,6	6.7	.042	6.9%	2.2%	3	1.9%	2.8%	5
	Driver	Night	2-3m/s^2 NegLon	1,8	9.1	.017	1.1%	0.6%	5	0.5%	.2%	5
	Driver	Night	3-4m/s^2 NegLon	1,8	7.2	.028	0.07%	0.06%	5	0.02%	0.02%	5

	Occupants	Time of day	Measure	*df*	*F*	*p-value*	Baseline	SD	n	Treatment	SD	n
Stage	Driver	Day	10-15mph >SL	1,6	11.6	.014	3.7%	3%	8	5.2%	4.3%	8
	Driver & Passengers	Day	Driver Seat Belt	1,8	7.7	.024	80%	18%	10	93%	11%	10

	Occupants	Time of day	Measure	*df*	*F*	*p-value*
Stage x Location	Driver	Day	4-5m/s^2 non-directional	1,8	5.4	.048*

Table 20. Speed Management Subsystem group vehicle data results. ***Note.* follow-up tests not significant.***

	Occupants	Time of day	Measure	*df*	*F*	*p-value*	Baseline	SD	n	Treatment	SD	n
Stage	Driver	Night	3-4 m/s^2 Non-directional	1,8	6.3	.037	0.3%	0.1%	10	0.8%	0.8%	10
	Driver	Night	4-5 m/s^2 Non-directional	1,8	8.1	0.02	0.006%	0.008%	10	0.08%	0.08%	10
	Driver	Day	5-10mph > SL	1,7	6.7	.036	12.1%	7.1%	9	5.3%	7%	9

Stage x Location	Occupants	Time of day	Measure	*df*	*F*	*p-value*
	Driver	Night	3-4 m/s^2 Non-directional	1,8	6.6	.033*

3.3. Cell Phone Subsystem

Overall, no significant differences were found between the treatment and baseline conditions for the Cell Phone Subsystem group. The lack of effects were likely attributable to the small sample size and general system function. There were five Maryland and two Minnesota participants in the Cell Phone Subsystem group. Due to a high level of false alarms, the Cell Phone subsystem was deactivated for 2 participants from Maryland (312 and 315) before the conclusion of the study. Their data were included in the following analyses. Results, averages, standard deviations and sample sizes for the Cell Phone Subsystem analyses are presented in Table 23.

Speeding Exceedance

Speeding Exceedance measures are reported as a percentage of miles driven with GPS coverage (GPS miles). There were significant effects of Location for the speed range between 5 mph and 10 mph above the speed limit (5-10 mph>SL) and between 10 mph and 15 mph above the speed limit (10-15 mph>SL). Results showed that participants from Maryland had a significantly greater percentage of GPS miles within both ranges.

G-Force Threshold Exceedance

There were significant main effects of location for several levels of the G-Force Threshold Exceedance measure. Results of the location analysis for nighttime driving without passengers indicated that participants from Minnesota had a higher percentage of miles when compared to participants from Maryland within the range 2 to 3 and 3 to 4 m/s^2 (non-directional). There were two occurrences when directionality showed significance differences due to location. At night without passengers, there was a significant effect of location on the percentage of total miles accelerating at a rate between 2 to 3 m/s^2 (PosLat). During the day there was a significant effect of Location for braking or slowing down at a rate between 3 to 4 m/s^2 (NegLon). For both significant findings for directional acceleration, Maryland participants had a higher percentage of total miles compared to Minnesota participants. The differences resulting from location highlight that participants drove differently at each location.

It should be noted that the results from the Cell Phone subsystem were influenced by false alarm rates (e.g., false cell phone detection). The increase in detection rates when participants were not using a cell phone likely impacted identifying significant differences when there were no differences. Furthermore, the small sample size likely impacted the statistical analyses (e.g., reduced power of the tests) and the interpretation of the findings. The number of alarms per participant for Minnesota and Maryland are presented in Appendix O. The cell phone counts vary based on participant and some of the data reflects high false alarm rates.

Table 21. Cell phone Subsystem group vehicle data results.

	Occupants	Time	Measure	*df*	*F*	*p-value*	MD	SD	n	MN	SD	n
Location	Driver	Night	5-10mph > SL	1,3	70.6	.004	18.4%	6%	3	2.3%	1%	2
	Driver	Night	10-15mph > SL	1,3	13.1	.036	9%	6%	3	0.1%	0.2%	2
	Driver	Night	2-3 m/s^2 PosLat	1,5	16.4	.01	9.1%	11.6%	5	1.2%	1.2%	2
	Driver	Night	2-3m/s^2 non-directional	1,5	12.7	.016	3.7%	3.2%	5	12.6%	3.3%	2
	Driver	Night	3-4m/s^2 non-directional	1,5	14.2	.013	0.5%	0.6%	5	2.9%	3.3%	2
	Driver	Day	10-15mph > SL	1,5	10.2	.024	10.5%	5%	5	1.3%	2%	2
	Driver	Day	3-4m/s^2 NegLon	1,5	11.3	.02	0.4%	0.4%	5	0.08%	0.07%	2
	Driver	Day	3-4m/s^2 non-directional	1,5	7.3	.042	0.7%	0.6%	5	1.8%	1.2%	2
	Driver & Passengers	Night	5-10mph > SL	1,3	12.1	.04	11.8%	10%	3	0.7%	0.08%	2
	Driver & Passengers	Night	10-15mph > SL	1,3	14.6	.05	7.1%	6.4%	3	0.002%	.004%	2

3.4. Parent and Teen Usability Results

Teens from Maryland along with at least one of their parents answered questions (Van der Laan et al., 1997) regarding their perceptions of the STC usefulness and satisfaction. Teens found the system useful, but were neutral with respect to overall satisfaction (see Figure 1 for a graphical representation of results). Teens commented the STC had reliability/false alarm issues that may have reduced perceived satisfaction. The Maryland teens found the STC useful and commented that drivers, especially novice ones, would probably benefit from STC use. Parents of teens found the STC both useful and satisfying. Maryland parents commented that despite some reliability issues the STC was useful for new drivers and helped avoid "problem/illegal" behaviors.

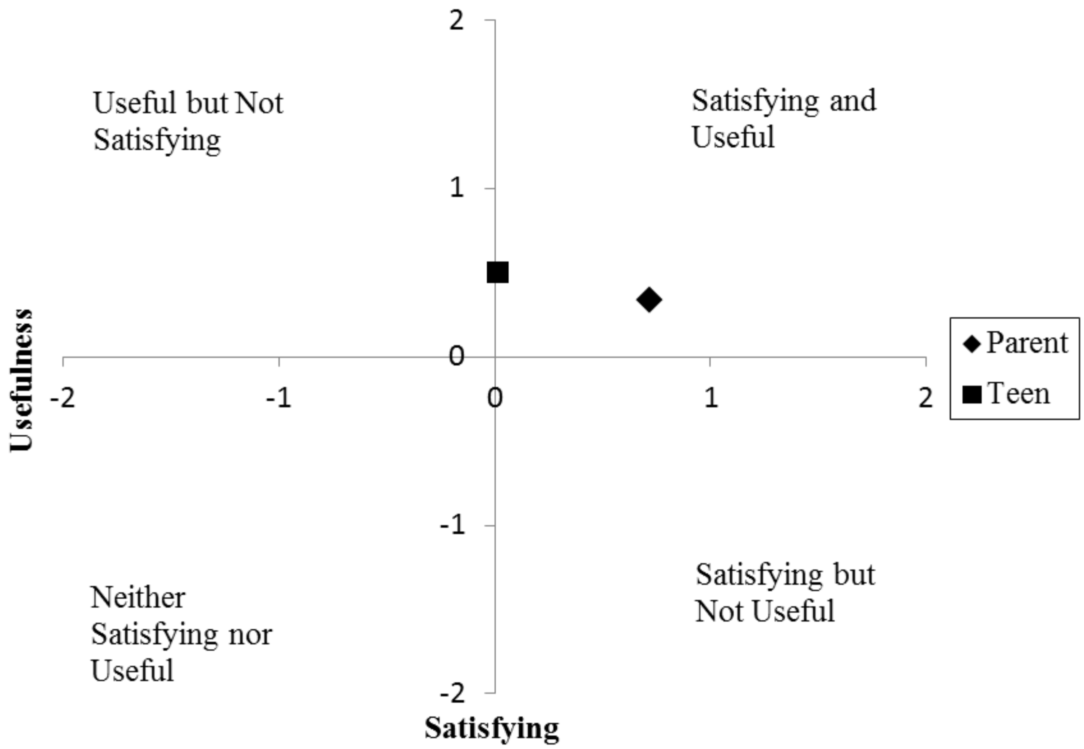

Figure 1. STC usefulness and satisfaction ratings for both teens and parents from Maryland.

Minnesota teen responses to the same set of questions were similar to the Maryland teens (see Figure 2 or a graphical representation). Minnesota teens found the STC a little unsatisfying but did find it useful. Teen comments indicated there were STC reliability and false alarm problems and that the STC had a tendency to drain vehicle batteries. Teens found the speed subsystem monitoring particularly useful as indicated by comments such as "made me more apt to pay attention to how fast I was going." Other comments supported the notion that the STC increased awareness of their driving task and "[being] kept in line" by the STC in terms of driving behavior. Minnesota parents found the STC to both useful and satisfying. General comments included "[having] a good experience with the STC, with a few reliability and false alarms issues."

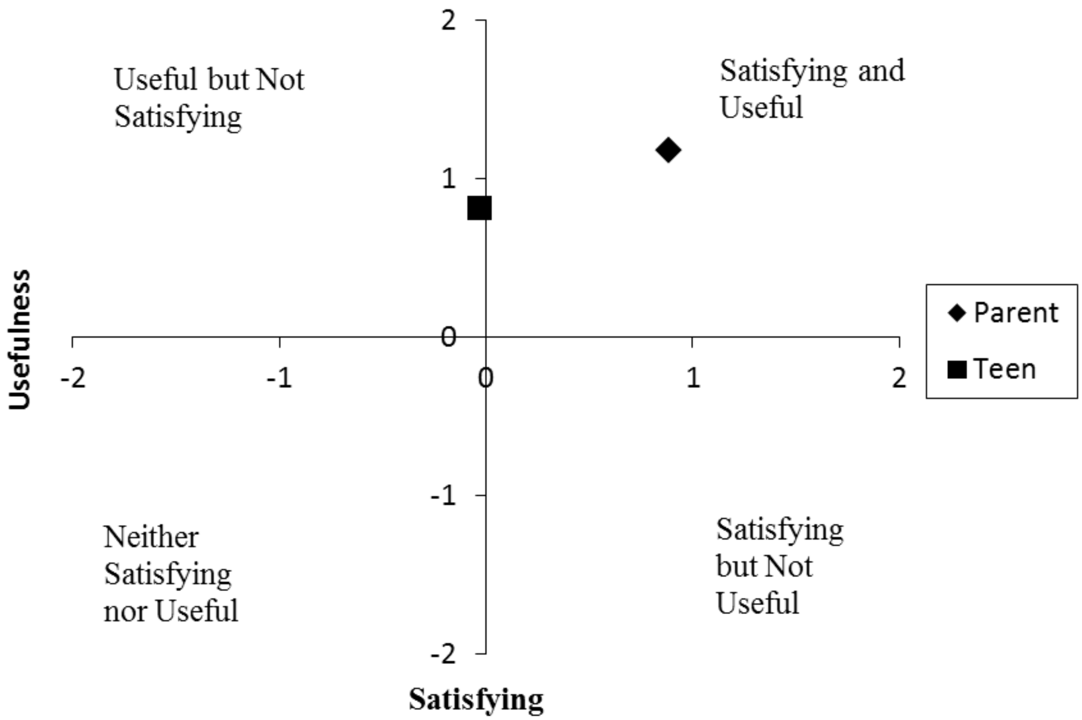

Figure 2. STC usefulness and satisfaction ratings for both teens and parents from Minnesota.

3.5. Teen Trust Results

Teens were presented with a series of trust questions that asked them about their opinions of safety, familiarity, dependability, and integrity with respect to their interaction with the STC. Teens were asked to indicate a score between zero (strongly disagree) and one hundred (strongly agree) based on the trust question presented to them (Appendix G). These scores were then averaged based on location (Minnesota, Maryland).

When teens were asked if the STC improved their driving their responses indicated that Location was an influencing factor. Teens from Maryland had an average of 54percent, which suggests that their responses were neutral regarding the STC's ability to improve driving. Minnesota teens were slightly more optimistic about STC improving their driving as indicated by the average response of 66 percent. When asked about their familiarity with the system, teens responded confidently they were familiar with STC regardless of location (Maryland 84% agreed and Minnesota 84.17% agreed). A difference in responses was seen between locations when teens were asked if they trusted the STC. The Maryland teens average was 49 percent when responding to the question, which suggests a neutral response while Minnesota teens average was higher at 70 percent. The results indicate that Minnesota teens had a higher level of trust in the system than Maryland teens.

Responses were mixed between the two teen groups when asked about the reliability of the STC. Maryland teens appeared to have encountered a greater level of system issues as indicated by the 45 percent average response rate when queried about system reliability while Minnesota teens were slightly higher with an average response of 62.92 percent. A system dependability question was asked and teens from both locations were neutral to slightly positive in their responses. The average response from Maryland teens was 53.33 percent (i.e., neutral). Minnesota teens slightly agreed when asked about STC dependability (M = 65.83%). Responses from teens in both locations indicated similarity when asked about STC integrity (Maryland 63.93% and Minnesota 66.67%).

3.6. Teen Attitudes and Safety Results

The majority of teens agreed (Maryland 20%, Minnesota 25%) or somewhat agreed (Maryland 46.7%, Minnesota 58.3%) that the STC improved their safety. When asked if the STC made them a better driver the responses varied based on geographic location. Twenty-five percent of Minnesota teens completely agreed and 50 percent somewhat agreed that the STC made them better drivers. Maryland teen drivers had a higher neutral response to the question (46.7%) when asked if the STC made them a better driver. Two of the trust responses did not vary due to location: System familiarity and confidence to drive without the STC. Teens were familiar with the STC regardless of location (Maryland reported 82.6% agreement compared to Minnesota's 88.2%), and were equally confident to drive without it (Maryland reported 90.0% average compared to Minnesota's 93.2%).

Table 4-8).

When the topic of STC unreliability was asked, responses varied based on location. Minnesota teens somewhat disagreed (58.3%) or were neutral in their responses (33.3%). Alternatively, Maryland teens expressed a greater diversity in responses either completely agreeing (13.3%) or somewhat agreeing (26.7%), or they were neutral (26.7%) about unreliability. Thirty-three percent of Maryland teens somewhat disagreed that the STC was unreliable. A closer inspection of the responses shows higher unreliability ratings for the speed subsystem specific to the Maryland teens compared to the other subsystems (e.g., cell phone).

Table 22. Teen responses to interacting and using the STC by location (percentage)

I view the Safer Teen Car system as…		Completely Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Completely Agree
A system that improves safety	Maryland	--	13.3	20	46.7	20
	Minnesota	--	--	16.7	58.3	25
A system that makes me a better driver	Maryland	6.7	13.3	46.7	26.7	6.7
	Minnesota	--	8.3	16.7	50	25
Unreliable in its operations	Maryland	--	33.3	26.7	26.7	13.3
	Minnesota	--	58.3	33.3	8.3	--
Requires specialized training and practice	Maryland	66.7	26.7	6.7	--	--
	Minnesota	50	33.3	16.7	--	--

Teen attitudes towards the STC were influenced by subsystem type and location (see Table 4-10). Minnesota teens attitudes on using the Maneuver subsystem were slightly more negative (60%) compared to the Maryland teens in the other categories. Minnesota teens had higher positive attitudes towards the Maneuver subsystem and were slightly positive (40%) or very positive (40%). The Minnesota teens in the cell phone condition rated their attitudes towards the STC very positive (100%) compared to their counterparts in Maryland, who were slightly positive (20%) or very positive (20%) towards the cell phone system. It should be noted that there were only 2 participants from Minnesota in the Cell Phone group and there were a few participants in Maryland who requested that the phone system be deactivated. Therefore, the results from the participants remaining in each of the cell phone groups that continued with the subsystem evaluation may appear overinflated due to small sample sizes. Comparisons to the other subsystems where each group has a larger number of responses may not be representative.

Table 23. Teen attitudes to driving with and without the STC system. Scores represent percentages within each group.

			Very Negative	Slightly Negative	Neutral	Slightly Positive	Very Positive
What is your attitude toward driving with STC?	Maryland	Cell Phone	--	20	40	20	20
		Maneuver	--	60	40	--	--
		Speed	--	20	60	--	20
	Minnesota	Cell Phone	--	--	--	100	--
		Maneuver	--	--	20	40	40
		Speed	--	--	60	40	--
What is your attitude towards driving without STC?	Maryland	Cell Phone	--	--	20	40	40
		Maneuver	--	--	20	60	20
		Speed	--	--	20	20	60
	Minnesota	Cell Phone	--	--	50	50	
		Maneuver	--	--	40	40	20
		Speed	--	20	60	--	20

When the entire teen sample was asked if the STC was beneficial the majority of teens (70.4%) responded that it was a "minor benefit," with some teens (22.2%) responding it was a "major benefit." Only two teens (7.4%) responded that the STC was of "no benefit."

When asked if the STC had changed the way they drove the majority of teens responded it "probably changed" (48.1%) or "definitely changed" (18.5%) their driving. Eighty percent of the Maryland teens using the speed subsystem responded it "probably changed their driving" (see Table 4-11).

Table 24. Teen comments regarding whether the STC changed their driving. Scores represent percentages within each group.

Did the STC change the way you drive?		**Definitely did not change**	**Probably did not change**	**Not sure**	**Probably changed**	**Definitely changed**
Maryland	Cell Phone	20%	40%	--	20%	20%
	Maneuver	20%	--	60%	20%	--
	Speed	--	20%	--	80%	--
Minnesota	Cell Phone	--	--	--	100%	--
	Maneuver	--	--	--	60%	40%
	Speed	--	20%	20%	20%	40%

A final question asked teens about their satisfaction with the STC. Teens responded positively to the overall satisfaction with STC with 40.7 percent of all teens being "somewhat satisfied" and 18.5

percent were “very satisfied.” However, teens also had issues with the STC as 25.9 percent were “somewhat dissatisfied” with the system (note: the remaining were neutral, 14.8%).

Table 25. Teen satisfaction with the STC system. Scores represent percentages within each group.

What is your over satisfaction with STC?		Not satisfied at all	Somewhat dissatisfied	Neutral	Somewhat satisfied	Completely satisfied
Maryland	Cell Phone	--	20	--	40	40
	Maneuver	--	80	--	--	20
	Speed	--	20	60	20	--
Minnesota	Cell Phone	--	--	--	50	50
	Maneuver	--	--	--	60	40
	Speed	--	20	20	60	--

3.7. Parent Usability Results

Parents of teens also completed questionnaires about the STC system. Main topics, similar to the ones explored with the teens were used. The first question asked parents whether they felt like the STC system would change their teens driving behavior. The majority of parents agreed that the STC would “probably change” (51.9%) or “definitely change” (14.8%) their son or daughters driving behavior. However, 4 parents were not sure if it changed behavior and 2 parents (7.4%) thought it “probably did not change” their teenagers driving behavior.

When parents were asked if they would recommend the STC system to other parents the responses were dependent on location. Maryland parents responded “yes” 83.3 percent of the time, commenting that the system was a good reminder of important driving skills and promotes safety. Minnesota parents responded “yes” at a lower rate (33.3%) with the majority responding “Yes, but with reservations” (53.3%). When the parents were asked whether they would recommend STC to other teens, the combined “yes” response from both groups was 88.9 percent. Parents also agreed unanimously (i.e., 100%) that the STC was not an invasion of privacy for their teens.

Parents were asked if they were satisfied with the STC. Overall, parents were either “somewhat satisfied” (55.6%) or “completely satisfied” (25.9%) with the STC. Parents were then asked if they would choose to purchase an STC if it were an option on a vehicle. Response differences occurred between locations with the majority of parents from in Minnesota (e.g., 75%) saying “I would pay.” Those remaining said they would take a free system (25%) if it was part of the vehicle package. Conversely, the majority of the parents from Maryland did not respond to the question (53.3%). Those that did respond were either interested in a free STC (33.3%) or didn’t want a STC (13.3%) at all.

A final discussion involved price points of the system. Again, there were differences in responses between the Minnesota and Maryland. The average price Maryland parents were willing to pay was M = $314.29 (SD=$128.17) whereas Minnesota parents were willing to pay an average of M =$257.14 (SD =$123.92).

3.8. Usability Unstructured Discussion Results

Both teens and parents of teens for each of the test locations provided their general feedback on the STC (see Appendices J and K). The responses gathered from the two testing locations were then organized into general categories that included:

- Awareness – the teen became aware or more aware of their driving related behavior;
- Reliability – STC reliability and general opinions;
- Change – suggestions for changing an element of the STC;
- Positive – comments gathered that were a positive experience with STC;
- Distraction – situations in which teens found themselves distracted by the STC;
- Following System – feedback indicating the teen, parent, or passenger followed STC instructions; and
- New – comments that suggest additional features or novel additions to the STC beyond its current functionality.

5.1.1. Excessive Maneuver Subsystem

Teens responded positively to the Maneuver subsystem. Responses included statements such as, "it made me realize that some of the maneuvers I made weren't always good," "the system made sure you didn't overly do something or be reckless," and "I was more cautious about my speed on turns." Detrimental elements of the system included distraction issues that included "10 seconds is too long for the warning," "the warning was startling," and "[the] alarm was jarring, short beeps are better." On occasion participants did not appear to couple the actual maneuver with the warning type and suggestions for STC improvement included "the tone should be replaced by the actual action – e.g., heavy braking or rapid lane change." Participants wanted more information about what action was associated with the maneuver alarm rather than the auditory tone and one icon.

3.8.1. Speed Management Subsystem

The response by participants to the speed warnings varied slightly, however the overarching theme was that the speed warning was effective and made teens more "aware of speed limits" and made at least one teen "change [his/her] driving as they didn't want to hear the warnings." Only a few teens found the warning to have a negative or distracting effect and commented "the warnings were jarring" or "the strong warning was distracting." Teens did have some reliability issues with the speed subsystem. Teens in rural locations had issues with the speed subsystem functioning in that "the speed limit does not appear very much" and "most of the roads I drove were not in the system" suggesting the speed database, though sufficient in most circumstances, may not provide information for all driver locations. Other issues encountered included discrepancies between posted speed limits and those on the system. In a few instances a teen encountered "the speed limit everywhere was 80 mph" (these instances were caused by a software bug between the interface and the map database). Teens and parents also had a number of future STC improvements (see e.g., Appendices J and K) that included displaying the current speed as a secondary source of information, increasing the tone/pitch of the warning as the speed was increasing, and monitoring the radio volume such that the warnings can be discernible without interference from music.

3.8.2. Seat Belt Detection Subsystem

When discussing the seat belt warning subsystem teens noted that the message was clear, helped them to establish a habit seat belt checks, and helped to reduce peer pressure as the system, not just the driver, required passenger seat belt use. Reliability was noted by participants as a large deficit of the seat belt subsystem functionality. Teens encountered "several false alarms" that included identifying non-existent people (e.g., "a backpack") or having several warnings after passengers had left the vehicle. A teen noted that the reminder phase of the seat belt warning was not "distinguishable from the motivator phase." Parents and teens suggested greater sensitivity for identifying actual passengers that in turn would increase trust and reliability of the system.

3.8.3. Context Subsystem

Responses to the context element of the STC were less obvious to teens than the other overt warnings (e.g., cell phone warning). A few comments were gathered from teens that recognized the system was active. One teen noted " [the system] was more sensitive at night." However, no teens encountered reliability or distraction issues with the context element of the system. Participants did offer system improvements in future iterations. Improvements included weather specific detection (e.g., snow/rain), increased precision in the detection of day/night limitations, tracking time of date to identify violations of "provisional periods," and reducing sensitivity somewhat to reduce the strong warnings (e.g., adjusting thresholds of the multiple inputs from teen car).

5.1.2. Teen Driver Identification Subsystem

Teens were also asked about the driver identification portion of the STC. Upon "start up" the STC asked (via the display) who was going the drive the vehicle. This feature was instituted to differentiate and potentially disengage the STC when an adult was using the vehicle. When parents were asked about the selection of adult mode, most responded they would never select it. Additional reliability issues were also encountered that included never being able to make a choice (e.g., the screen no initiating) or the selection screen appearing while the vehicle was already in motion. Additional issues included not seeing the selection screen because it was "not visible long enough" and "although the RFID card was present…never saw the selection system." These points suggest that the screen, upon start-up of the vehicle, needs to remain on longer to give participants ample time to make an appropriate selection. Future STC changes proposed by users included an RFID key (rather than a card), having selectable features for adult mode, and perhaps using a passcode instead of an RFID.

5.1.3. Cell phone Subsystem

According to the qualitative results, teens generally followed the STC instructions with respect to the cell phone condition. Teens commented that the cell phone warning, both auditory and visual, was easily understood and comprehended. For some teens the warning was "disruptive" and "bothersome" that resulted in participants "not using my cell phone as much." These responses suggest a potentially effective STC that discourages teens from using their cell phone while driving. However, this was influenced by reliability that both Minnesota and Maryland teens commented on. Users encountered situations where the STC was instructing them to discontinue cell phone use when they were not using their cell phone and commented "[the warning was] going off unnecessarily." These instances of false alarms appear to have decreased trust to some extent in the

STC as one teen noted "Cell phone warning consistently going off, generally unreliable." This also lead to some distraction issues as teens noted "the malfunctioning cell phone aspect was difficult to deal with" and "…[the cell phone warning] was distracting." When asked about future STC changes, a parent suggested "detect texting" and "make the system tuned to the inside of the car" with respect to localizing the cell phone detection within the vehicle.

It should be noted that these responses included participants that encountered a high number of false alarms (i.e., system alerts without the teen using the cell phone) at each location and two participants in MD that had the subsystem deactivated due to participant requests.

4. Discussion

The primary purpose of the preliminary functional road test of the STC subsystems was to identify teen driver behavior changes and usability perceptions associated with each STC subsystem. A secondary goal was to identify potential issues and suggest design changes for the subsystems prior to the full STC evaluation. To accomplish these goals each subsystem was installed on teen vehicles at two separate testing locations. Data was collected during a 4-week period that included a 2-week baseline stage, during which the subsystems were inactive, and a 2-week Treatment stage when the subsystems were active. Differences between the baseline and Treatment stages provided insight into the effectiveness of the STC subsystems. Subjective feedback provided additional information about system effectiveness and utility.

The results from the 4-week functional road test suggest the concepts of the subsystems were appealing to teens and parents of teens. The objective data provided positive but less insightful information compared to the subjective feedback. Overall, there were some positive subsystem impacts to teen driving behavior; however this was tempered by technological issues.

5.2. Excessive Maneuver Subsystem

A number of differences occurred for the Speeding Exceedance measure for the Excessive Maneuver subsystem for the Stage and Location comparisons. A significant increase in the percentage of speeding miles at 10-15 mph above the speed limit was found when the Excessive Maneuver subsystem was activated. When the data set was further explored the general trend, though not significant for the other speed ranges, was for higher speeds for all speed ranges when the Excessive Maneuver subsystem was active (e.g., see Figure 3). Again, why teens were speeding in these categories and what the Maneuver subsystem contributed to this behavior is not clear.

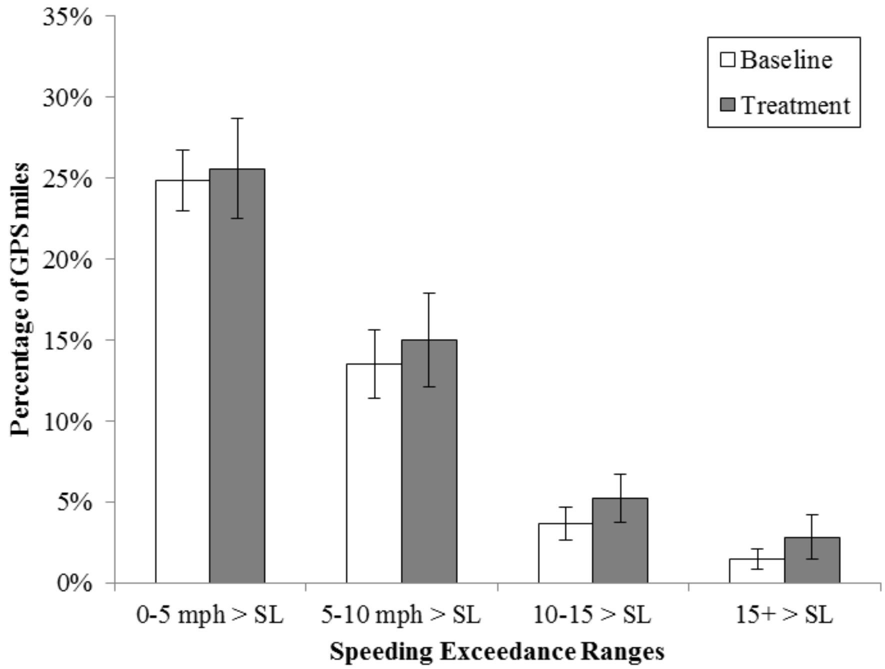

Figure 3. Excessive Maneuver subsystem group mean speeding rates for daytime driving. Error bars represent ± 1 standard error of the mean.

Differences in driving styles identified in the cell phone group also occurred in the Excessive Maneuver subsystem group. For example, in the Excessive Maneuver subsystem group Maryland teens had a greater percentage of miles speeding when compared to the Minnesota teens. This effect was also found in the cell phone group. These common differences found in two separate subsystem groups suggest an overall variation in driving styles between Maryland and Minnesota. These differences were perhaps due to traffic flow, roadway types, or other elements that were not accounted for in the analyses of the vehicle data (e.g., valid GPS mileage differences between the locations).

Teens stated that the feedback from the Excessive Maneuver subsystem made them more aware of the safety implications of their driving maneuvers. The teens appreciated that the subsystem acted as a reminder about the how easily drivers can lose control when a combination of improper speed and turning behaviors occur. A parent of one teen recounted that while driving with the STC active the teen executed a maneuver that the parent, who was in the passenger seat, thought was reckless and dangerous. The parent suggested the maneuver was inappropriate to which the teen responded "Do not worry [parent], if that maneuver was dangerous the system would have told me." The system did not provide feedback in this situation so the teen felt the maneuver was appropriate. The parent suggested tuning the system sensitivity to ensure that feedback is delivered during such circumstances. Teens also stated it was difficult to understand what type of maneuver violation caused the warning to occur (e.g., hard braking, mild breaking, cornering, etc.). The confusion is likely attributed to inconsistent threshold changes due to other less reliable systems (e.g., passenger presence). This may have resulted in inconsistent feedback for identical maneuvers in similar situations.

Although there was confusion regarding what maneuvers lead to the feedback, the subjective responses by teens provides some support regarding the value of the Excessive Maneuver subsystem. However, the vehicle data does not provide clear conclusions that the Excessive Maneuver subsystem affected driving behavior by reducing excessive maneuvers.

5.3. Speed Management Subsystem

Overall teens sped less after the STC was activated for this group. A significant difference was identified between the baseline and Treatment stages for teen drivers speeding 5 to 10 mph above the speed limit during the day. Teen drivers reduced the amount of speeding miles in this range by 7 percent after the Speed Management subsystem was activated. This result suggests that the Speed Management subsystem lowered teen speeding behavior for this category. An interesting practical effect identified in the data was a general trend to reduce speeding behavior in almost all of the speed categories. Figure 4 is a plot of the other speed categories and shows that almost all speed categories saw a reduction in speeding behavior. The trend suggests the Speed Management subsystem influenced teens to reduce their speeding behavior that indicates that speed feedback may help teens reduce speeding behavior.

When discussing the Speed Management subsystem with teens they indicated it made them more aware of speeding behavior. Teens also commented that the strong verbal warning was distracting as it was too loud and very abrupt. Teens also indicated that the mild warnings were sometimes missed because they were masked by vehicle noise. Future suggestions for the Speed Management subsystem included increasing the volume of the warnings that are coupled to the vehicular speed so speed warnings can be identified more easily at higher speeds. Teens also wanted the feedback to occur under more circumstances and for it to be more noticeable.

Finally, for some teens in Minnesota, the Speed Management subsystem did not provide feedback for every drive. The speed database used to identify and compare speeds was extensive, however there were areas not covered within the database. If coverage would have been broader for these participants their appreciation of the feedback may have been stronger as they would have had more exposure to the function of the speed subsystem. Moreover, this also identifies potential weaknesses with the technology implemented, such that gaps in the speed database undermine the effectiveness of the speed subsystem.

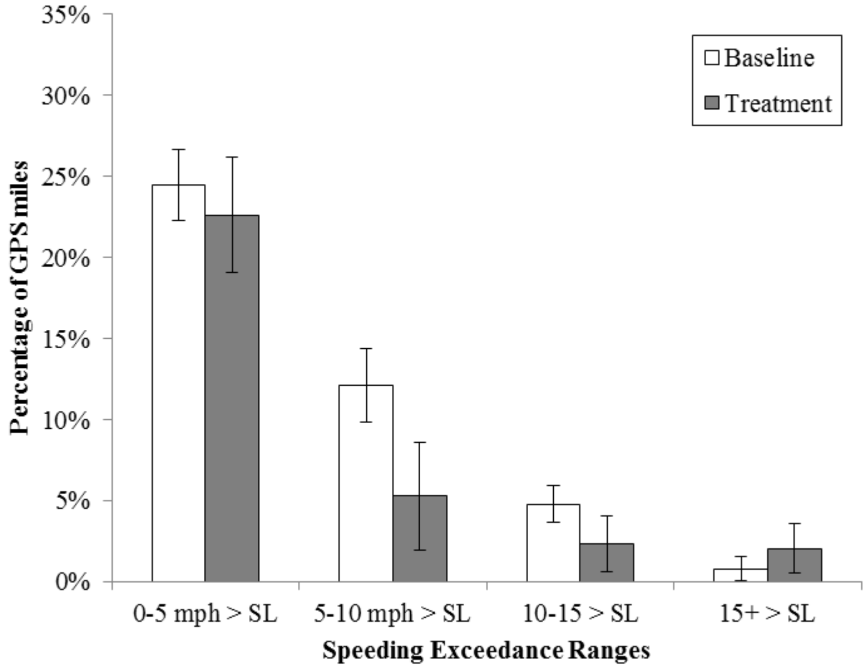

Figure 4. Mean speeding exceedance rates day driving, Speed Subsystem group. Error bars represent ± 1 standard error of the mean.

5.4. Cell Phone Subsystem

Maryland and Minnesota teens showed a difference in the rate of G-force threshold exceedance at various levels. Minnesota teens had higher combined maneuver values (i.e., lateral and longitudinal values combined) than the Maryland teens. While these findings suggest that driver behavior was different between locations the impact of cell phone subsystem is not known.

The intent of the cell phone subsystem was understood by teens and parents, however the technological instability of the system appeared to have reduced both trust in the system and perceived system usefulness. There were a few occasions when the system correctly identified cell phone use and teens indicated they complied with the feedback. However, this was tempered by teens remarking the subsystem providing undeserved feedback. At the time of this report there are marginally better systems available in terms of reliability, however these are currently cost prohibitive to deploy on a large scale. Furthermore, the results suggest that for a cell phone subsystem to be well received by teens and parents vehicle manufacturers will need to install highly reliable cell phone detection technology.

Lastly, the objective measures were limited by the general sample size of the groups. There were only two Minnesota participants in this group and, depending on the measure and data integrity, the Maryland group also experienced a restricted sample size. These sample size issues were also compounded by a requirement to recruit teens with specific phone types (e.g., non-smart phone users). With the proliferation and adoption of smart phone technology any future iterations of the cell phone detection subsystem will require detecting these types of phones. As a result, the objective data gained from this group did not provide strong insight into the influence of a cell phone subsystem on driver behavior.

5.5. Seat Belt Detection Subsystem

The Seat Belt Detection subsystem provided increased seat belt compliance rates specific to the Excessive Maneuver subsystem. Seat belt compliance rates increased by 13 percent compared to baseline conditions for drivers with passengers during daytime conditions. The increase in seat belt compliance rate was most likely due to the seat belt system feedback and indicates enhanced safety benefits for the STC. In addition to the rate increase several teens stated that the seat specific auditory component helped them to enforce passenger seat belt compliance.

A general review of the data for the seat belt subsystem across groups and conditions (e.g., day or night) was also conducted to identify general seat belt compliance rates between baseline and treatment conditions. Seat belt compliance rates increased for drivers (only) by eight percent during the treatment period. Furthermore, seat belt compliance rates increased for passengers (e.g., range: 0.5%-5.6%) during the treatment period. It should be noted that increased false alarms (e.g., detecting a seat belt violation when none were present) were higher for passengers than for drivers and thus compliance rates were influenced. These general results in addition to the significant effects show a positive influence of the subsystem on teen driving behavior.

5.6. Passenger Presence Subsystem

There were no discernible effects specifically attributable to the Passenger Presence subsystem. The subsystem did affect the Excessive Maneuver and Speed Management subsystem thresholds that were lowered if there were three passengers in the vehicle. Only one participant suggested that the safety requirements for driving with or without passengers should be equivalent. This participant's statement suggests that a consistent safety model would have been more appropriate than a differential safety model that changed relative to the quantity of vehicle occupants.

5.7. Teen Driver Identification Subsystem

There were no reliable vehicle-based measures on the usage of the Teen Driver Identification subsystem. However, comments by teen participants indicated that the selection screen component of this system did not operate consistently. The inconsistency influenced the overall use of the subsystem resulted in the STC defaulting to STC mode. A few comments by parents indicated that the current STC functions (e.g., seat belt, speed management, excessive maneuver, and cell phone warnings) could be applicable to parents and thus they did not see a need for parent mode. Participants also noted that the use of an RFID card was not a preferred method for identifying if a parent was present in the vehicle. Participants suggested alternative approaches that included a key with an RFID chip or a passcode to be entered prior to starting the vehicle.

5.8. Context Subsystem

Results of the current work indicated a general benefit for STC use during daytime conditions but limited benefits during nighttime conditions. This finding is interesting given the fact that a greater change in behavior may have been expected given the greater rate of warnings and feedback during nighttime conditions as a result of lowered subsystem thresholds. However, we suspect that conservative driving behaviors are more prominent during nighttime conditions and thus the absolute number of warnings and feedback would be reduced at night. Less conservative driving behaviors during daytime conditions would allow teens to interact with and benefit from STC feedback. A positive finding was that participants reported that there was a noticeable difference in how sensitive the Excessive Maneuver and Speed Management subsystems were at night compared to day. Participants also commented that other contextual elements would be helpful. For example, feedback adjustments for variable road conditions due to variations in weather were part of the conceptual design of this subsystem and participants agreed that these elements would be valuable if technologically feasible. However, including this functionality in the full STC evaluation is beyond the scope of this project.

5. Recommendations for the Full STC Evaluation

The results provided substantial insight into the elements of the STC that could be refined for the full STC evaluation. Some of the recommendations were generated based on feedback from human factors practitioners. Human factors practitioners viewed the STC systems from a demonstration perspective and gave direct feedback based on the elements they saw. The demonstration event occurred at the 54th Human Factors and Ergonomics Society Annual Meeting in San Francisco in September 2010.

- **Driver Identification Subsystem**: Subjective data and input from the unstructured discussions indicated that participants did not like the RFID card, rarely selected adult mode, and found little value in adult mode. The feedback suggests that the STC features were often active, even when a parent was present. As such vehicle manufacturers may consider not offering this feature or providing a different mechanism to activate parent mode. They also stated that to make the adult mode more useful the amount of time for selecting the mode should be increased. Comments from a demonstration to Human Factors practitioners recommended a change to the title of the Safer Teen Car adult mode to something that would not denote ageism. However, we recommend keeping the current implementation for the full STC evaluation to validate these findings.

- **Excessive Maneuver Subsystem**: In summary, participants found that the Excessive Maneuver subsystem feedback was directionally ambiguous, jarring due the abruptness of the tone, and distracting due to duration of the feedback. Comments from Human Factors practitioners indicated that feedback duration was too long and could be better coupled with the elements of the maneuver (i.e., to make the feedback more clear they suggested the duration of the warning match the duration of the event). For the current study, when the maneuver warnings occurred, participants may not have known what maneuver caused the feedback or how to correct their driving behavior to ensure the feedback did not occur again.

  Considering the current results, modifying the maneuver system feedback seems appropriate. At a minimum, the feedback should be changed to reduce the jarring and distracting qualities as well as to make the feedback association more clear. As proposed by the Human Factors practitioners, directional feedback presented after the maneuver may reduce distraction, eliminate the jarring effect, and increase clarity. For example, after a maneuver occurs the feedback could provide a notice that a recent braking, cornering, or accelerating maneuver was excessive and why? The STC could state "Your left turn was aggressive" 2 to 3 seconds after the maneuver was detected. Although the data from the current study does not offer insight towards when the feedback should be presented several seconds of lag time prior to presenting maneuver feedback may be appropriate. If lag-time is implemented then the feedback would have to be more qualitative. However, a drawback to this implementation is that teen drivers may not make a strong association between an excessive maneuver and the subsystem feedback.

Finally, although worthy of note, but of low value to the underlying purpose of the STC, the maneuver icon was confused with "slippery when wet" by participants and Human Factors practitioners. Training and associating the icon with maneuvers may eliminate confusion. The Human Factors practitioners also stated the background color could be changed to elicit a sense of urgency. However, given that the warning is tightly coupled with the driving maneuver performed by the teen changes to the subsystem are not recommended for the full study. For the full STC evaluation we recommend keeping the current subsystem. An example of both lateral and longitudinal maneuvers that may trigger the warning will be provided verbally to the teen drivers during the introduction of the STC.

- **Speed Management Subsystem**: The results indicated generally lower speeds when the Speed Management subsystem was active. However, a few participants commented that the mild warning was easy to ignore and the strong warning was at times startling and distracting. To address subjective concerns future iterations for the speed feedback could include providing subtle hints regarding the speed limit exceedances. Graded or staged feedback that changes in intensity relative to the extent the driver is speeding may be less distracting, shocking, or startling compared to an abrupt verbal warning. If implemented, the graded feedback could increase in frequency and loudness as the driver increases their speed beyond the limit. However, because the Speed Management subsystem was shown to be effective in the current study we recommend retaining all features of the current system in the full STC evaluation. A separate future evaluation comparing current warnings and a graded warning is recommended.

- **Cell Phone Subsystem**: Qualitative results from the current study indicate the concept of providing a warning when a driver uses a cell phone may help to reduce cell phone usage. Two participants stated that despite reliability issues feedback from the cell phone subsystem reduced their phone usage. While the cell phone subsystem reliability was not directly measured it was estimated to be around 35 percent. Since it is not possible to implement a cell phone sensor capable of perfect or near perfect (e.g., >90%) reliability this system should be excluded from the upcoming full STC evaluation.

- **Passenger Presence Subsystem**: Unreliable vehicle data and subjective comments from teens offer limited insight into how the Passenger Presence subsystem affected driving behavior and acceptance of the STC. The low reliability of the system likely contributed to a perceived low reliability of the Seat Belt Detection subsystem and likely influenced the validity of the Excessive Maneuver and Speed Management subsystems. Actual reliability level for the PIR sensors was not measured. For the full STC evaluation the reliability of the passenger detection sensors will be increased.

- **Seat Belt Detection subsystem**: The vehicle data and the subjective data indicated that the Seat Belt Detection subsystem was effective at increasing seat belt compliance. Although there were several false warnings due to malfunctions of the Passenger Presence subsystem, the utility of the seat belt warnings was demonstrated in this study. Participants stated it was useful. No further changes are recommended.

- **Context Subsystem**: The context system was reliable and functioned appropriately and so there are no recommendations for changing this system.

- **Adaptive features**: The data suggest there may have been some confusion due to the adaptive features that change Excessive Maneuver and Speed Detection warning thresholds. The thresholds and adaptive nature of the subsystems were explained during the review process at installation. An example included telling participants how the speed subsystem responded if other adaptive features also occurred. For example, participants learned that the threshold for speeding were reduced based on the number of occupants in the vehicle, whether they were driving at night, and also if passengers were wearing their seat belts. The only subsystem not impacted by these thresholds was the cell phone group. The additive nature of the STC was not well perceived by participants as only a few commented on the restrictive nature of the system at night compared to daytime driving. Additional training on the STC may be required for users to understand how the additive quality of the adaptive features changes Excessive Maneuver and Speed Detection warning thresholds. Simplifying the example to just the speed situation will likely help participants understand the additive nature of the STC threshold levels and potential impacts on the other systems. The intent is to pick a speed limit level and tell participants based on the input of other subsystems how this will effect when they get feedback from the system. This example will be emphasized during the participant introduction section for the full STC evaluation.

- **Sample Size:** Sample size for the current subsystem evaluation likely influenced the statistical power of the analyses. The research and analysis plan indicates 30 participants will be recruited for the full evaluation. A power analysis for this sample size shows that 30 participants will provide adequate power for teen driver specific variables. Furthermore, the entire sample will be exposed to all of the subsystems as opposed to a subset of subsystems and they will interact with STC for a greater period of time. The combination of exposure and increased sample size are expected to provide improved statistical rigor and interpretations.

6. Limitations

While some results from the current study show some promise for several subsystems a number of limitations were also encountered that directly affected the potential practical implications of the results. The following list provides some of the data collection challenges and subsystem implementation issues encountered during the four-week preliminary functional road test that should be considered when interpreting the results of this study. As such results of the current evaluation should be considered tentative until confirmatory evidence can be obtained from the full STC evaluation.

- Alternative cell phone detectors were tested during the development of the STC cell phone subsystem with the final sensor being chosen based on cost, reliability, and ease of installation into vehicles. Shortly after installation it became apparent that the reliability of this sensor was not robust (e.g., ~35%) that resulted in a high rate of false warnings and may have potentially impacted the perceived trust in the cell phone subsystem. In addition, the results of the study were based on a small sample size that likely impacted the power of the statistical analyses.
- The cell phone detection sensor for the current STC implementation could not reliably detect signals from smart-phones (e.g., iPhones, BlackBerries, Android phones) if the "data push" feature was active. To address this issue the research team restricted participant selection to those who did not have a smart-phone. This approach created a participant recruitment challenge in Minnesota because most teens in the Minnesota recruiting areas owned and used smart-phones. To address this issue the University of Minnesota research team expanded the size of the recruitment area however this did not lead to an increase in participants with appropriate phones.
- The passenger presence detection sensors exhibited high rates of false passenger presence detection (e.g., indicating a passenger was present when no passengers were present). This may have been due to the various in-vehicle heat signatures that interfered with the sensor detecting the heat signature of a passenger. Additional errors associated with the passenger presence detection sensor included seat positions that had low clearance and sensors that were occasionally knocked out of position. When the sensors exhibited a false passenger presence this may have confused teen drivers (e.g., no passenger present but feedback indicating a passenger detected). False passenger presence for seat positions with an unfastened buckle reduced the thresholds for the Maneuver and Speed subsystems resulting in unnecessary warnings. There was no cost effective way to remove data associated with false passenger detection.
- A number of GPS signal losses occurred during the data collection process that occasionally reduced the quality and quantity of valid speed data. The GPS signal losses affected the analysis of measures that depended on the speed limit. The implication is that some speed related dependent measures were occasionally not available. Drivers may have been speeding for an unknown portion that cannot be accounted for due to issues with GPS. Similarly, the adaptive features that relied on GPS were not available without a signal, thus the Excessive Maneuver subsystem functions varied due to the signal loss and this could have contributed to confusion regarding what caused the feedback to occur.
- The number of participants used in the current study reflected the practicality of an initial functional road test for STC subsystems. It is important to note that significant differences from such a small sample size may actually reflect comparisons between one or two people within a group (e.g., cell phone group) that may influence the strength of the results. The full ten-week STC effort will better guide any statistical and practical implications of the STC for teens drivers.
- Results of the study indicated that the STC collected smaller than expected amounts of data for a few participants during the study. The cause of this was due to computer malfunctions that required a system reboot and the fact that some participants drove significantly fewer miles that expected. This resulted in fewer than expected data points for some participants that impacted the strength of the analyses.

7. References

Brookland, R., & Begg, D. (2011, April). Adolescent, and their parents, attitudes towards graduated driver licensing and subsequent risky driving and crashes in young adulthood. *J Safety Res.*;*42*(2):109-15. doi: 10.1016/j.jsr.2011.01.002. Epub 2011 Mar 1.

Centers for Disease Control and Prevention. (n.d.) Injury prevention & control: Motor Vehicle safety – *Teen Driver: Fact Sheet*. Retrieved April, 11, 2011 from www.cdc.gov/MotorVehicleSafety/Teen_Drivers/teendrivers_factsheet.html.

Compton, R. P., & Ellison-Potter, P. (2008, July). *Teen Driver Crashes: A Report to Congress.* (Report No. DOT HS 811 005). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/Traffic%20Injury%20Control/Articles/Associated%20Files/811005.pdf

Farmer, C. M., Kirley, B. B., & McCartt, A. (2010). Effects of in-vehicle monitoring on the driving behavior of teenagers. *Journal of Safety Research, 41*, 39-45.

Insurance Institute for Highway Safety. (n.d.) Fatality Facts 2008: Teenagers. Retrieved April, 11, 2011 from www.iihs.org/research/fatality_facts_2008/teenagers.html

Insurance Institute for Highway Safety. (n.d.) Young driver licensing systems in the U.S. – Maryland. Retrieved July 1, 2011 from www.iihs.org/laws/GraduatedLicenseStateLaws.aspx?StateAbbr=MD

Insurance Institute for Highway Safety. (n.d.) Young driver licensing systems in the U.S. – Minnesota. Retrieved July 1, 2011 from www.iihs.org/laws/GraduatedLicenseStateLaws.aspx?StateAbbr=MN

Lee, S. E., Simons-Morton, B. G., Klauer, S. E., Ouimet, M. C., and Dingus, T. A., (2011, July). Naturalistic assessment of novice teenage crash experience. *Accid Anal Prev.*; *43*(4): 1472–1479. doi: 10.1016/j.aap.2011.02.026

Lerner, N., Jenness, J., Singer, J., Klauer, S., Lee, S., Donath, M., Manser, M., & Ward, N. (2010). *An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers.* (Report No. DOT HS 811 333). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Human%20Factors/Reducing%20Unsafe%20Behaviors/%EF%BB%BFDOT%20HS%20811%20333.pdf

Mayhew, D. R., Simpson, H. M., & Pak, A. (2003). Changes in collision rates among novice drivers during the first months of driving. *Accident Analysis and Prevention*, *35*, 683-691.

Williams, A. F. and Shults, R. A. (2010). Graduated Driver Licensing research, 2007-Present: A review and commentary. *Journal of Safety Research*, *41*, 77-84.

Van der Laan, J. D., Heino, A., & de Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research part C, 5*(1), 1-10.

This report also included information and data from unpublished reports delivered to NHTSA as interim Task Orders, as follows:

Gorjestani, A., Menon, A., Arpin, A., Cheng, P., Huey, R., Lerner, N., & Jenness, J. (2010). An evaluation of a prototype Safer Teen Car: Determine enabling technologies that meet the functional and interface specifications (Task 2 Report). DTNH22-08-D-00115, Task Order 2.

Manser, M., Graving, J., Rakauskas, M., Creaser, J., Lerner, N., Jenness, J., & Huey, R. (2010a). An evaluation of a prototype Safer Teen Car: Specify subsystem functions and their performance requirements (Task 1 Report). NHTSA DTNH22-08-D-00115, Task Order 2.

Manser, M., Graving, J., Rakauskas, M., Lerner, N., Jenness, J., and Huey, R. (2010b). An evaluation of a prototype Safer Teen Car: Develop and review data collection and analysis plan (Task 3 Report). NHTSA DTNH22-08-D-00115, Task Order 2.

Appendix I-1: Teen Demographic Questionnaire

Participant #: _______

Driving History & Opinions (Teen)

Complete the following items regarding your driving history and your current driving behaviors, and driving records such as tickets and crashes. Your answers will be completely confidential. If you feel leave it blank any items you feel uncomfortable answering. Please tick <u>one</u> box for each item.

1. Your date of birth: MM: ________ / DD: ________ / YYYY ________

2. Your sex:
   - ☐ Male
   - ☐ Female

3. Please state the month and year when you obtained your provisional driving license:

   MM: ________ / YYYY ________

4. How would you rate yourself as a driver?
   - ☐ Above average
   - ☐ Slightly above average
   - ☐ Average
   - ☐ Slightly below average
   - ☐ Below average

5. How often (days per week) do you typically drive?
   - ☐ Every Day
   - ☐ 5 or 6 days per week
   - ☐ 3 to 5 days per week
   - ☐ 1 or 2 days per week
   - ☐ Less than 1 day per week

6. On average, how many miles do you currently drive every week? ______________________

7. What type of vehicle will you drive most often?
   - ☐ Motorcycle
   - ☐ Passenger Car
   - ☐ Pick-Up Truck
   - ☐ Sport utility vehicle
   - ☐ Van or Minivan
   - ☐ Other, briefly describe: ______________________________________

Appendix I-2: Teen Acceptance Questionnaire

Participant #: _______

Acceptance Scale: Teen

Think about how you felt during the last two weeks of driving with the Safer Teen Car system. Please indicate your opinion of the Safer Teen Car system by marking one box for each pair of items.

For example, if you thought the messages were very easy to use but required a lot of effort to learn, you might respond as follows:

Easy	☒ ☐ ☐ ☐ ☐	*Difficult*
Simple	☐ ☐ ☐ ☒ ☐	*Complex*

"I thought the Safer Teen Car was…"

Useful	☐ ☐ ☐ ☐ ☐	Useless
Bad	☐ ☐ ☐ ☐ ☐	Good
Nice	☐ ☐ ☐ ☐ ☐	Annoying
Irritating	☐ ☐ ☐ ☐ ☐	Likeable
Assistive	☐ ☐ ☐ ☐ ☐	Worthless
Undesirable	☐ ☐ ☐ ☐ ☐	Desirable
Helpful (w/ Alertness)	☐ ☐ ☐ ☐ ☐	Sleep-inducing
Pleasant	☐ ☐ ☐ ☐ ☐	Unpleasant
Effective	☐ ☐ ☐ ☐ ☐	Superfluous

Appendix I-3: Teen Trust Scale

Participant #: _______

Trust Scale

Think about how you felt during the last two weeks of driving with the Safer Teen Car. Please place a vertical line through each scale to mark your agreement with each statement below:

The performance of the system enhanced my driving safety.

0 Strongly Disagree	50	100 Strongly Agree

I am familiar with the operation of the system.

0 Strongly Disagree	50	100 Strongly Agree

I trust the system.

0 Strongly Disagree	50	100 Strongly Agree

The system is reliable.

0 Strongly Disagree	50	100 Strongly Agree

Participant #: ________

The system is dependable.

0 Strongly Disagree — 50 — 100 Strongly Agree

The system has integrity.

0 Strongly Disagree — 50 — 100 Strongly Agree

I am confident in my ability to drive without the system.

0 Strongly Disagree — 50 — 100 Strongly Agree

Appendix I-4: Teen Usability Ratings

Participant #: _______

Usability (Teen)

You have driven your vehicle that was fitted with a Safer Teen Car system. Based on your driving experience with this system please indicate how much you agree with the following statements, in comparison to unassisted driving:

"I view the Safer Teen Car system as…"

	Disagree Completely	---	---	---	Agree Completely
A system that improves safety	☐	☐	☐	☐	☐

Please explain your answer: ………………………………………………………………….…………
……………………………………………………………………………………….…………
……………………………………………………………………………………….…………

A system that makes me a better driver	☐	☐	☐	☐	☐
A source of confusion	☐	☐	☐	☐	☐
Increasing mental (and visual) effort	☐	☐	☐	☐	☐
Increasing driver comfort	☐	☐	☐	☐	☐
Creating difficulties on curves	☐	☐	☐	☐	☐
Encouraging faster than normal speeds	☐	☐	☐	☐	☐
Making the driver less vigilant	☐	☐	☐	☐	☐
Making the driver less stressed	☐	☐	☐	☐	☐
Making the passengers less stressed	☐	☐	☐	☐	☐
Encouraging over-confidence in drivers	☐	☐	☐	☐	☐
Unreliable in its operations	☐	☐	☐	☐	☐
Requires specialized training and practice	☐	☐	☐	☐	☐

Participant #: _______

Fill in the space provided or mark the box for the response that you feel best represents your opinion of the entire Safer Teen Car system (including all subsystems and notifications). When completing these items, try to compare your experience using the Safer Teen Car system to what you experience when driving without the system:

1. What could the Safer Teen Car system have done differently to improve the on-screen messages?

   ....
   ....
   ....

2. What could the Safer Teen Car system have done differently to improve the audio messages?

   ....
   ....
   ....

3. Did you notice anything out of the ordinary with the display or data collection system while in the vehicle with your teen driver?
   If so, please explain.

   ....
   ....
   ....
   ....

4. How would you describe your attitude toward driving WITH the Safer Teen Car system?
   - Very positive
   - Slightly positive
   - Neutral
   - Slightly negative
   - Very negative

5. How would you describe your attitude toward driving WITHOUT the Safer Teen Car system?
   - Very positive
   - Slightly positive
   - Neutral
   - Slightly negative
   - Very negative

Participant #: _______

6. Do you think you paid more or less attention to driving while using the Safer Teen Car system compared to driving without it?

   Much more attention
   ☐ A little more attention
   ☐ No change
   ☐ A little less attention
   ☐ Much less attention

   Please explain the reason(s) for your answer.
   ....
   ....
   ....

7. Having tried it, do you think the Safer Teen Car system had any benefits for you as a driver?
   ☐ Major benefits
   ☐ Minor benefits
   ☐ No benefits

   Please explain the reason(s) for your answer.
   ....
   ....
   ....

8. Please briefly describe the most difficult aspects of driving when using the Safer Teen Car system:

   ....
   ....
   ....

9. Do you feel that the Safer Teen Car system changed the way you drove?
   ☐ Definitely changed
   ☐ Probably changed
   ☐ Not sure
   ☐ Probably did not change
   ☐ Definitely did not change

   If so, how did the Safer Teen Car change the way you drove?
   ....
   ....
   ....

Participant #: _______

10. How willing would you be to use the Safer Teen Car system as a tool to help you improve your safe driving skills while you have your provisional license (i.e., graduated driver's license--GDL)?
    - ☐ Completely willing
    - ☐ Somewhat willing
    - ☐ Neutral
    - ☐ Somewhat unwilling
    - ☐ Completely unwilling

11. Rate your overall satisfaction with the Safer Teen Car system?
    - ☐ Completely satisfied
    - ☐ Somewhat satisfied
    - ☐ Neutral
    - ☐ Somewhat dissatisfied
    - ☐ Not satisfied at all

12. Additional comments:

....
....
....
....
....
....

Appendix I-5: Parent Usability Questionnaire

Participant #: _______

Usability (Parent)

The following items ask you about your observations of your teens driving with the Safer Teen Car system.

1. What could the Safer Teen Car system have done differently to improve the on-screen messages?

   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

2. What could the Safer Teen Car system have done differently to improve the audio messages?

   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

3. Did you notice anything out of the ordinary with the display or data collection system while in the vehicle with your teen driver?
   If so, please explain.

   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

4. Do you feel that the Safer Teen Car system would change the way your teen drives?
   - ☐ Definitely changed
   - ☐ Probably changed
   - ☐ Not sure
   - ☐ Probably did not change (skip number 5)
   - ☐ Definitely did not change (skip number 5)

   If so, how did you think the Safer Teen Car system changed the way s/he drove?
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

Participant #: _______

5. Would you recommend the Safer Teen Car system to other PARENTS?
   - ☐ Yes
   - ☐ Yes, but with reservations.
   - ☐ No

Please explain:

....
....
....
....

6. Would you recommend the Safe Teen Car system to other TEENS (including your own)?
   - ☐ Yes
   - ☐ No

7. Did you feel like the Safe Teen Car system was an invasion of your teen's privacy?
   - ☐ Yes
   - ☐ No

`If you responded yes, Please explain:

....
....
....
....

8. Rate your overall satisfaction with the Safe Teen Car system?
   - ☐ Completely satisfied
   - ☐ Somewhat satisfied
   - ☐ Neutral
   - ☐ Somewhat dissatisfied
   - ☐ Not satisfied at all

9. If you were purchasing a new vehicle today and the Safe Teen Car system was an option, much would you be willing to pay for it?
   - ☐ I would not pay for it but would take a free one.
   - ☐ I would pay $__________________________
   - ☐ Don't want.

Participant #: ________

10. Additional comments:

....
....
....
....
....
....

Appendix I-6: Parent Acceptance Scale

Participant #: _______

Acceptance Scale: Parent

Think about how you felt during the last two weeks of driving with the Safe Teen Car system. Please indicate your opinion of the Safe Teen Car system by marking one box for each pair of items.

For example, if you thought the messages were very easy to use but required a lot of effort to learn, you might respond as follows:

Easy	☒	☐	☐	☐	☐	*Difficult*
Simple	☐	☐	☐	☒	☐	*Complex*

"I thought the Safe Teen Car was…"

Useful	☐	☐	☐	☐	☐	Useless
Bad	☐	☐	☐	☐	☐	Good
Nice	☐	☐	☐	☐	☐	Annoying
Irritating	☐	☐	☐	☐	☐	Likeable
Assistive	☐	☐	☐	☐	☐	Worthless
Undesirable	☐	☐	☐	☐	☐	Desirable
Helpful (w/ Alertness)	☐	☐	☐	☐	☐	Sleep-inducing
Pleasant	☐	☐	☐	☐	☐	Unpleasant
Effective	☐	☐	☐	☐	☐	Superfluous

Appendix I-7: The Number of Days and Mileage in Baseline and Treatment

Condition	Participant	Days of Baseline (total miles, Speed limit known miles)	Days of Treatment (total miles, Speed limit known miles)	Miles speed limit not known
Minnesota Group 1	112	14 (205, 103)	13 (284, 174)	212
	114	17 (284, 183)	16 (415, 252)	263
	Total	*31 (489, 286)*	*29 (699, 427)*	*475*
Minnesota Group 2	120	13 (133,78)	12 (111, 61)	105
	121	13 (537, 338)	12 (250, 126)	323
	122	14 (494, 314)	14 (468, 264)	384
	125	14 (388, 238)	18 (460, 336)	274
	126	11 (174, 108)	13 (550, 419)	197
	Total	*65 (1727, 1075)*	*69 (1838, 1206)*	*1284*
Minnesota Group 3	130	12 (369, 241)	8 (182, 119)	191
	131	13 (172, 73)	13 (215, 106)	208
	132	13 (278, 176)	14 (339, 238)	203
	133	12 (209, 144)	9 (114, 62)	117
	135	5 (95, 73)	11 (106, 75)	54
	Total	*55 (1123, 707)*	*55 (956, 600)*	*772*
Maryland Group 1	311	8 (227, 163)	14 (149,75)	138
	312	6 (123, 67)	15 (298, 146)	207
	313	14 (603, 459)	18 (1078, 789)	433
	314	8 (173, 117)	3 (83, 61)	77
	315	9 (201, 141)	6 (48, 40)	67
	Total	*45 (1327, 948)*	*56 (1655, 1,111)*	*922*
Maryland Group 2	321	13 (190, 142)	12 (166, 120)	95
	322	9 (104, 66)	12 (123, 66)	95
	323	10 (465, 0)	9 (144, 0)	608
	324	14 (182, 86)	12 (131, 89)	138
	326	15 (169, 115)	22 (276, 206)	124
	Total	*61 (1110, 409)*	*67 (840, 481)*	*1059*
Maryland Group 3	331	7 (102, 72)	11 (210, 122)	117
	332	11 (186,113)	16 (327, 158)	242
	333	12 (214, 140)	14 (228, 138)	165
	334	10 (78, 32)	17 (211, 111)	146
	336	14 (254, 201)	11 (200, 120)	133
	Total	*54 (833, 558)*	*69 (1176, 650)*	*801*

Appendix I-8: Vehicle Miles traveled with RFID

Condition	Participant	Total miles (RFID)	GPS Miles (RFID)	Percent GPS miles excluded
Minnesota Group 1	112	709 (220)	462 (185)	40%
	114	940 (241)	652 (217)	33%
Minnesota Group 2	120	283 (39)	174 (35)	20%
	121	1,435 (648)	745 (282)	38%
	122	1,122 (160)	705 (127)	18%
	125	938 (90)	640 (66)	10%
	126	749 (25)	550 (23)	4%
Minnesota Group 3	130	610 (59)	411 (50)	12%
	131	493 (107)	266 (87)	33%
	132	696 (79)	483 (69)	14%
	133	341 (18)	220 (14)	6%
	135	331 (130)	262 (115)	44%
Maryland Group 1	311	390 (14)	247 (9)	4%
	312	434 (13)	225 (11)	5%
	313	1,681 (0)	1,247 (0)	[1]
	314	267 (12)	188 (10)	5%
	315	1,117 (868)	803 (621)	77%
Maryland Group 2	321	422 (66)	302 (41)	13%
	322	346 (119)	230 (97)	42%
	323	1,358 (750)	0 (0)	*
	324	313 (0)	175 (0)	[1]
	326	490 (45)	358 (75)	10%
Maryland Group 3	331	313 (2)	195 (0)	0.2%
	332	553 (40)	301 (30)	10%
	333	471 (28)	290 (12)	4%
	334	288 (0)	143 (0)	[1]
	336	457 (3)	324 (3)	1%
	TOTAL	17,547 (3,776)	10,598 (2142)	20%

*Note: *denotes that there were zero GPS miles. [1]denotes that there were zero miles with an RFID marker.*

Appendix I-9: Selection Screen usage

Condition	Participant	Selection Screen	Adult Mode	STC
Minnesota Group 1	112	21	20	19
	114	19	8	37
Minnesota Group 2	120	2	0	2
	121	8	0	9
	122	3	0	5
	125	2	3	0
	126	0	0	0
Minnesota Group 3	130	0	0	1
	131	1	0	3
	132	0	0	1
	133	0	0	0
	135	8	0	11
Maryland Group 1	311	7	0	10
	312	0	0	0
	313	0	0	0
	314	3	0	2
	315	36	49	38
Maryland Group 2	321	4	3	8
	322	4	0	4
	323	8	0	34
	324	1	0	1
	326	7	0	12
Maryland Group 3	331	1	0	1
	332	2	0	3
	333	2	2	1
	334	1	0	1
	336	0	0	0
	TOTAL	140	85	203

Appendix I-10: Vehicle Miles Traveled night and day

Condition	Participant	Day Miles	Night Miles
Minnesota Group 1	112	429	279
	114	495	444
Minnesota Group 2	120	126	157
	121	910	525
	122	777	345
	125	456	482
	126	434	316
Minnesota Group 3	130	200	410
	131	331	163
	132	449	247
	133	172	169
	135	120	212
Maryland Group 1	311	246	143
	312	115	319
	313	664	1016
	314	125	142
	315	437	680
Maryland Group 2	321	185	237
	322	112	234
	323	772	586
	324	91	222
	326	260	230
Maryland Group 3	331	108	205
	332	178	376
	333	240	231
	334	87	202
	336	155	303
	TOTAL	8,672	8,875

Appendix I-11: Warning counts when system was active

Condition	Subject	Mild Speed Warning	Strong Speed Warning	Maneuver Warning	Cell Warning	Reminder Seat belt warning	Motivator phase seat belt warning	Passenger Seat belt warning
Minnesota Group 1	112	X	X	X	64(13)	21(26)	33(57)	134(141)
	114	X	X	X	459(321)	34(33)	40(33)	131(84)
Minnesota Group 2	120	X	X	14(9)	X	15(20)	16(17)	10(15)
	121	X	X	7(10)	X	37(31)	44(26)	45(50)
	122	X	X	111(238)	X	32(45)	46(81)	230(451)
	125	X	X	17(13)	X	0(0)	28(7)	16(8)
	126	X	X	4(8)	X	37(32)	57(95)	61(24)
Minnesota Group 3	130	65 (229)	10(188)	X	X	11(43)	12(41)	14(43)
	131	33(53)	22(8)	X	X	8(4)	15(4)	22(14)
	132	187(212)	80(129)	X	X	23(29)	40(48)	32(41)
	133	37(88)	28(30)	X	X	11(36)	6(24)	8(12)
	135	124(51)	16(29)	X	X	1(2)	10(2)	5(13)
Maryland Group 1	311	X	x	X	13,898	6(21)	9(23)	46(117)
	312	X	X	X	383	100(4)	174(5)	69(20)
	313	X	X	X	1,139	0(0)	2(6)	118(29)
	314	X	X	X	129	8(19)	9(46)	7(12)
	315	X	X	X	335	14(22)	22(47)	52(343)
Maryland Group 2	321	X	X	15	X	26(41)	24(30)	43(140)
	322	X	X	14	X	8(18)	8(25)	20(42)
	323	X	X	139	X	25(60)	147(184)	74(15)
	324	X	X	8	X	12(18)	32(105)	6(2)
	326	X	X	34	X	18(11)	35(59)	17(40)
Maryland Group 3	331	123	174	X	X	7(9)	54(8)	94(66)
	332	209	171	X	X	39(18)	42(20)	176(153)
	333	70	87	X	X	2(0)	238(40)	61(19)
	334	106	86	X	X	24(10)	52(15)	43(14)
	336	54	1	X	X	6(1)	8(14)	9(25)

**Note: Brackets denote baseline data.*

Appendix I-12: Rural Unstructured Discussion Responses

System	Category	Comment
Cell Phone	Distraction	"bothersome while driving in congested traffic" "The audio messages were off" "Buzzer and alarms were too much"
	Following system suggestions	"…warning disrupted my phone calls." "when making necessary phone calls the warnings were bothersome."
	Positive	"image was understood" "I used my phone less" "It helped with awareness of other vehicles as it seemed the system went off for other drivers"
	Reliability	"It would tell me to stop using my phone when I wasn't…" "Lots of false alarms"
	System Change	"Make the system tuned to the inside of the car"
Context	New concept	"Use ABS computer to measure traction and provide traction feedback"
	System Change	"Would be good to include snow to adjust maneuver warning according to what traction may be like" "would be good to include rain" "weather would be the most beneficial context feature" "Should be more precise - I drive safer to school in the AM, but less safe after school for a variety of reasons, gotta get to work, peer influence, etc."
Driver Identification	Following System Instructions	"Never selected Adult car." "There seems to be no purpose for adult mode." "…Would never select adult car."
	Reliability	"Message initiation was not the same each time I entered the car- sometimes the adult screen would show up, mostly not." "while teen drove the beginning screen showed more often to give us a choice as to who is driving" "selection screen came up while driving on the highway" "The selection screen was not visible long enough, needs more time to make a selection ("I usually missed it because I was getting in my seat, buckling and all that.." "Although the RFID card was present… never saw the selection system"
	System Change	"An RFID key would have been better than the card." "A passcode would have been better than a card" "Since some of the features would be useful for more than just teens, the adult mode should allow for selecting features."

System	Category	Comment
Speed	Awareness	"…became more aware of speed limits"
	Distraction	"The strong warning was distracting." "The stronger warning caused anxiety while merging" "The strong warning was startling"
	Following system suggestions	"The strong speed warning was forceful and caused me to slow down but the mild warning was pretty ineffective and easily ignored." "…Concerned that the highway speed may be lower than the speed of average traffic, which causes a dilemma for the driver in choosing a safe speed choice: abide by the system or traffic?"
	Positive	"…Paid more attention because I had to watch the speed limit." "A benefit… kept me from speeding"
	Reliability	"The speed limit did not appear very much" "Most of the roads I drove were not in the system." "The speed limit did not always match the posted speed limit." "The speed limit was often offset from the location of the signs."
	System Change	"Provide a display of the current speed." "Provide a gradual notification of speed limit" "A warning should occur prior to approaching a school zone" "Provide a subtle beep when the speed limit changes" "There should be a continuous beep that increases in frequency relative to the amount the driver is speeding" "There should be a simple way to acknowledge and bypass the warning to reduce distraction and frustration." "Present the speed range." "A warning could occur at the high end of the speed range"
Seat Belt	Distraction	"The voice was unnecessarily annoying."
	Following system Suggestions	"Helped to make sure everyone was buckled." "Everyone buckles their seat belt so the system was annoying and not useful."
	Positive	"Messages were clear" "I now have a habit to check all seat belts" "Since the driver is responsible for seat belt compliance, it was helpful for the system to alert passengers so the driver doesn't have to do so."
	Reliability	"several false alarms" "At 55mph there were no seat belt warnings" "Magnets came loose" "It provided seat belt warnings several minutes after dropping someone off." "Reminder phase was not distinguishable from the motivator phase"

Maneuver System	Awareness	"It made me realize that some of the maneuvers I made weren't always good" "Increased awareness of poor maneuvers"
	Distraction	"10 seconds is too long for the warning" "At first the warning caused extra stress" "The warning was startling" "The maneuver warning should not occur during harrowing driving"
	Following System Instructions	"It was difficult to make turns that agreed with the system" "…maneuvers were safe unless the system warnings went off"
	Positive	"Maneuver" "Audio messages were clear." "I was more cautious about my speed on turns" "I paid more attention to my acceleration on turns so I wouldn't have to hear the beep again" "This would be useful for all drivers"

Appendix I-13: Urban Unstructured Discussion Responses

System	Category	Comment
Cell Phone	Distraction	"Cell phone warning was distracting because of the false alarms" "The malfunctioning cell phone aspect was difficult to deal with" "Cell phone alert kept going off and it was distracting"
	Following system suggestions	"I would not use my cell phone as much" "Easy to understand"
	Positive	"It kept me off my phone and that was good" "Appropriate when not a false alarm"
	Reliability	"Cell phone warning constantly going off, generally unreliable." "False alarms for cell phone" "It went off unnecessarily sometimes"
	System Change	"Cell phone beep a bit high pitched" "Cell phone monitor needs to detect texting" "Add GPS navigation to the screen"
	Awareness	"Encouraged safer driving" "Made [teen] more aware"
Context	Awareness	"Noticed it was more sensitive at night [restrictive]"
	System Change	"Too sensitive at night, when 1-2mph over strong warning activated" "Track time of day and when teen violates provisional period"
Driver Identification	Reliability	"I was never able to select a button"
Speed	Awareness	"Changed her driving as she didn't want to hear warnings." "STC made her more aware of speed (rather than keeping up with traffic)" "It told me exactly when I was going too fast so I slowed down kept me alert"
	Distraction	"The warnings were jarring"
	Following system suggestions	"Made me slow down" "Made me realize I needed to go slower on certain roads"
	Positive	"It made me pay closer attention to how fast I was driving" "I was constantly correcting my speed to stay just at the limit." "Liked the posted speed limit on the display screen"
	Reliability	"At one point it said the speed limit was 80mph everywhere" "Wrong limit was posted sometimes"
	System Change	"Radio volume monitoring" Parent suggested "Volume control" "Post vehicles speed on the display"
Seat Belt	Following system Suggestions	"Made me more aware of passenger seat belt use" "Seat belt reminder most useful, good reminder for the driver to enforce"

	Positive	"I don't like to tell my friends to put their seat belts on but with the system alerting them I didn't have to" "It allowed me to make sure my passengers and I were all safe by using our seat belts"
	Reliability	"Several false alarms" "It would say my backpack was a person not wearing a seat belt, also after a person leaves the car it would still think they're there"
	Awareness	"Encouraged asking passengers to buckle up. Made her more "aware of passengers"'
Maneuver System	Distraction	"Alarm too jarring, short beeps better" "Icon and noise might be a distraction"
	Following System Instructions	" I made sure to go slowly around turns and if I had passengers that they would buckle up"
	Positive	"The system made sure you didn't overly do something or be reckless."
	System Change	"The tone should be replaced by the actual action e.g., heavy braking or rapid lane change"
	Awareness	"Maneuver warning not effective for him, but for other's he knows."

Appendix J:

Evaluation of a Prototype Safe Teen Car: Final Specifications
Task 7 Interim Report

Submitted to:

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This appendix can be cited separately using the following suggested APA format citation:

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Table of Contents

1. Background and Objective

The current project addresses the serious problem of risky teen driving behaviors that may contribute to crashes during the initial stages of licensure. The goal of the project was to develop and evaluate a prototype teen driver support system (i.e., Safer Teen Car) that would motivate teens to reduce risky driving behaviors by providing feedback about risky behaviors and providing vehicle adaptations.

To accomplish this goal the project consisted of eight tasks that included:

Task 1: Specifying subsystem functions and their performance requirements;

Task 2: Determining enabling technologies that meet the functional and interface specifications;

Task 3: Developing and reviewing data collection and analysis plan;

Task 4: Conduct evaluation of subsystems;

Task 5: Building and demonstrating to NHTSA the prototype Safer Teen Car;

Task 6: Conducting stakeholder outreach and prototype vehicle evaluations, developing a parent/teen information program;

Task 7: Documenting final specifications; and

Task 8: Generating final report, conduct stakeholder meetings.

Based on previous teen driver research and efforts within the initial project tasks the following subsystems were proposed to address teen driver risk factors.

- Teen Driver Identification Subsystem
- Seat Belt Detection and Enhanced Reminder Subsystem
- Passenger Presence Subsystem
- Speed Monitoring and Feedback Subsystem
- Excessive Maneuver and Feedback Subsystem
- Cell Phone Use Detection and Mitigation Subsystem
- Driving Context Subsystem

Specific details that informed the development of these subsystems and evaluation efforts are provided in the project reports for Task 1 and 4 and are contained in final project report (see Manser et al., 2010a and Graving et al., 2011, Manser et al., 2012).

The purpose of the current work was to provide a series of specifications relative to the Safer Teen Car (STC) design that serve as the deliverable for Task 7. They are a culmination of the entire research effort and were informed by the initial tasks and subsequent testing phases of the project. In addition, information contributing to their development was obtained from evaluation participants, the research team, subject matter experts, and feedback from members of NHTSA. The information contained in this document should serve as the basis for future development and deployment Safer Teen Car systems by vehicle manufacturers. The specifications are more aptly termed recommendations as the current work is an initial step in STC development and further research may indicate alternative system designs. The information contained in this document is organized according to individual subsystems employed in the STC evaluation.

1. Teen Driver Identification Subsystem

For the Safer Teen Car to be effective and alert teen drivers to specific risk-taking behaviors the system needs to identify if the person driving the car should be presented with the appropriate STC feedback and vehicle adaptations. As an example, the STC needs to recognize other drivers (e.g., parents or siblings) who use the vehicle and allow them to disengage the system if the STC functionality is not required. To identify non-STC drivers the prototype STC contained a Teen Driver Identification subsystem that employed a "smart key" that could be recognized by the STC. The smart keys utilized radio frequency identification (RFID) technology to communicate with the STC when the key was within the proximity of the vehicle and, if present, provided drivers with a choice between "Parent Mode" and "Teen Mode." In this way parents and siblings not requiring assistance from the STC could opt out of the STC feedback and vehicle adaptations.

There is a need to identify driver type and thus it is recommended that future OEM-based STC's include teen driver identification functionality. Results from the full STC evaluation provide the basis for the specifications for the Teen Driver Identification subsystem functionality.

1.1. Operational Specifications

- The Teen Driver Identification subsystem shall retain a method by which a teen cannot circumvent the STC while still allowing for modal selection (e.g., parent and non-teen modes). Defaulting to Safer Teen Car mode in the current study was an effective way to prevent one method of circumvention.
- The technology used to indicate to the STC that a non-teen driver is present should be minimally invasive. OEM's currently incorporate RFID technology into vehicle keys or fobs that is minimally invasive and this method could easily be used to identify if a driver is a teen or adult.
- Upon detecting an adult key the Teen Driver Identification subsystem should display a forced choice decision prior to initiating STC mode. This ensures that a parent or guardian can determine if they would like the vehicle to be operated in teen or adult mode. For example, a parent may wish to be a passenger with a teen but without the STC active.
- Mode choice should be displayed for an extended period of time such that choice selections can be more easily recognized and then made. Ten seconds was employed in the STC evaluation and this is recommended as a minimum timeframe.
- Teen Driver Identification subsystem reliability should be maximized so that the modal selection is presented only when a non-teen driver is present.
- There should exist more than one selection method to accommodate situations when non-teen drivers do not have (e.g., lost) their teen driver identification technology. As an example, a password protected mode selection screen could be presented to drivers upon vehicle startup. In addition, if the Teen Driver Identification subsystem were an element of the technology needed to operate a vehicle (e.g., RFID technology in vehicle keys or key

card access to start a vehicle) the adverse effect of STC key loss would be mitigated.

- Modal selection between STC and Adult mode should be provided via a visual display. The modal selection could be presented easily on in-vehicle displays that are becoming increasingly common within the center stack of vehicles. Figure 18 presents an example visual interface. Voice selection of mode could also be employed but the system should allow for reliable identification of the need to select a mode and reliable mode selection.

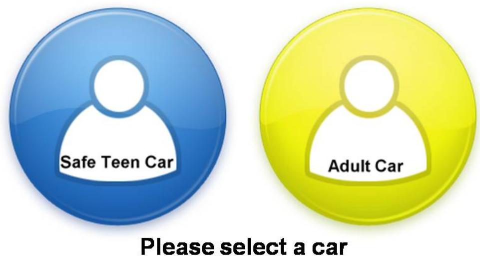

Figure 5. Example Teen Driver Identification subsystem in-vehicle display to indicate a choice between Safer Teen Car and Adult Car modes.

2. Passenger Presence and Detection Subsystem

The Passenger Presence and Detection subsystem provides information regarding the presence of occupants in the front and rear seating positions that is used to modify feedback thresholds and vehicle adaptations for allied subsystems (e.g., Excessive Maneuver and Feedback subsystem). Within the full STC evaluation passenger presence was accomplished through tape switches embedded in seat covers installed on the front passenger seat and on the rear seating positions. The presence of a driver was assumed based on vehicle ignition and vehicle motion. Vehicle manufacturers already employ passenger presence sensors most typically in the form of weight sensors within a seat. The use of this technology could easily serve as one indication of passenger presence for a STC produced by vehicle manufacturers as long as misdetection rates (i.e., due to the presence of objects and not people) are minimal.

2.1. Operational Specifications

- The interface and operation of this subsystem should not be noticeable to a driver and passengers except at vehicle startup as a status indicator. The status check could be part of the startup procedures during normal vehicle system checks (e.g., check engine). If the Passenger Presence and Detection subsystem is non-functional or deemed to be malfunctioning, the adaptive nature of the subsystem should be disengaged to avoid false alarms.
- System check status could be presented as an icon on the dash along with typical vehicle status check icons (e.g., water temp warning, oil pressure warning, seat belt warning) or on the display employed to present STC information. The easiest and more cost effective method would be to include the status check on a display as this only requires computer programming to include the information versus adding wiring and an indicator lamp to a dash.

- To the greatest extent possible passenger presence detection accuracy should be maximized to reduce the rate of false alarms and misses. Improved accuracy will improve driver acceptance for this subsystem and allied subsystems. As such the Passenger Presence and Detection subsystem could be integrated with the seat belt detection subsystem such that the two subsystems complement each other and provide redundant information regarding passenger presence.
- Passenger presence hardware in rear seats is not omnipresent in the vehicle fleet and thus there is a need to employ passenger presence detection in these seating positions to support STC deployment. Passenger effects are very pronounced for teen drivers.

3. Seat Belt Detection Subsystem

The Seat Belt Detection subsystem reminds and motivates teen drivers and passengers to use their seat belts. There were two types of audible (voice and tone) warnings for the driver seat position. A *reminder phase* ("Buckle seat belt.") that occurred if the driver buckle was not fastened when the car was stationary and a *motivator phase* ("Driver, buckle seat belt.") that cycled every 30 seconds if the driver remained unbuckled while the car was in motion. The two audible warnings were paired with a visual icon and text stating "Driver Buckle Seat Belt." There was a unique audible for the front passenger, driver-side rear passenger, and passenger-side rear passenger seat positions (e.g., "Driver-side rear passenger, buckle seat belt" for the passenger position in the rear behind the driver). The passenger warnings were accompanied by a visual icon and text stating, "Passenger Buckle Seat Belt." The two-level system enhances seat belt use while at the same time minimizing annoyance. The prototype STC employed micro-switches attached to vehicle seat belt stanchions and buckles to determine seat belt engagement at each occupant location. In contrast to this approach vehicle manufacturers have already instituted reliable seat belt detection technology into the vehicle fleet that could be employed for STC use. Based on the results of the full STC evaluation the following specifications are recommended for the Seat Belt Detection subsystem when teen driver mode is selected via the Teen Driver Identification Subsystem.

3.1. Operational Specifications

- Results of the full STC evaluation indicated sustained seat belt compliance for drivers and improved seat belt compliance for rear passengers during STC use. Based on these tentative findings it is recommended that vehicle manufacturers employ a reminder and motivator seat belt detection subsystem similar to the one employed in the STC evaluation.
- The STC system should make communication of seat belt non-use obvious to all vehicle occupants. This provides opportunity and motivation for others (especially teen peers) to encourage the non-user(s) to buckle up.
- A verbal reminder (e.g., "Buckle seat belt") and visual icon should be presented after ignition if the driver is unbuckled. A verbal reminder (e.g., Driver, buckle seat belt") and a visual icon should be presented if the vehicle is in motion and a driver is unbuckled.
- Passengers should receive a unique audible for the front passenger, driver-side rear passenger, and passenger-side rear passenger seat. The passenger warnings should also be accompanied by a visual icon and text stating, "Passenger Buckle Seat Belt."
- The visual icon could be presented through the use of existing in-vehicle displays, preferably the one employed for STC information.

- A continually cycling motivator phase should begin approximately 15-20 seconds after ignition or when the vehicle begins to move if the driver remains unbelted. Vehicle movement can be assessed using existing vehicle speed information residing on the CAN-bus.
- The motivator phase should be stopped when the vehicle is no longer moving to reduce the presence of inappropriate warnings.
- In addition to the existing motivator phase actions, the STC vehicle adaptation could lock out the infotainment system if the driver remains unbelted. A message that indicates the infotainment system is locked out should be presented. Control of the infotainment system (e.g., on, off, volume) is becoming increasingly common with vehicle manufacturers as these functions are controlled increasingly through electronic versus mechanical (e.g., knobs, dials) methods. Vehicle manufacturers could easily include computer control of the radio functions based on seat belt status.
- It is recommended the Seat Belt Detection and Passenger Presence and Detection subsystems be coupled such that redundant seating information can be exchanged between the subsystems and thus increase the accuracy and reliability of the Seat Belt Detection subsystem. The inclusion of this feature is possible given that information from both of these subsystems reside on the vehicle CAN-bus. This feature would require additional programming and testing by vehicle manufacturers.
- The reminder phase should include a visual icon that can provide driver or passenger specific text (e.g., see Figure 19) in addition to a voice reminder as outlined above. The visual icon and auditory reminder should be seat specific (e.g., driver and/or passengers) to enhance seat belt compliance (Lerner et al., 2010). Determining seat belt non-compliance for individual seating positions may require additional vehicle modifications by the manufacturers.

Figure 6. Seat Belt Detection subsystem visual display.

4. Speed MONITORING AND FEEDBACK Subsystem

The STC included a Speed Monitoring and Feedback subsystem that compared a teen driver's current speed via on-board CAN-bus information against the posted speed limit that was obtained by referencing a teen driver's GPS location against a roadway database containing posted speed limits. Depending on the degree of speeding over the limit and the presence of additional risk factors (e.g., passenger presence) the Speed Monitoring and Feedback subsystem provided feedback and vehicle adaptations. The feedback consisted of a graded warning to teen drivers using both visual and auditory information. A mild warning was presented after the speed limit was exceeded by a small amount (e.g., 2 mph above the speed limit). The warning consisted of a short tone. A stronger warning was presented at a higher speed threshold (e.g., 10 mph above the posted speed limit) and consisted of a loud "buzzer" paired with an instruction that indicated "Speeding Violation." A loud buzzer sound was chosen to motivate teens to avoid the sound during future driving experiences. In addition, during the stronger warning period the STC display presented a red speed limit icon to teen drivers to indicate unsafe driving speed (see Figure 20). The degree to which teen drivers exceeded the speed limit was used as a factor that informed and was informed by the adaptive nature of the STC. For example, if a teen was speeding the thresholds for the Excessive Maneuver and Feedback subsystem were decreased. The research effort indicated that that in some situations teen driver behaviors benefited from the inclusion of the Speed Monitoring and Feedback subsystem. Implementation of this subsystem by vehicle manufacturers would require (1) using existing vehicle-based speed information from the CAN-bus, (2) obtaining a roadway database that contains associated posted speed limit information, and (3) developing the software to compare current speed against the posted speed identified in the roadway database. Certainly one obstacle would be item two, however, many new vehicles offer as standard equipment navigation devices that contain a database of posted speed limits. The main obstacle is then finding a method to access and maintain this information.

4.1. Operational Specifications

1. Provide teen drivers with information regarding the current posted speed limit with a persistent visual display in the vehicle. Evaluation participants found this information to be useful and potentially facilitated interactions with the STC.
2. Monitor compliance with known speed limits on roadways and provide two levels of feedback to the driver consistent with that employed during the STC evaluation. A mild warning may beprovided when the posted speed limit has been exceeded by a small amount to inform drivers when they are beginning to speed. The STC evaluation employed a 2 mph threshold that was well received by drivers but vehicle manufacturers should consider mild warnings at different speeds. A critical question is whether to warn a teen driver after they have exceeded the posted speed limit by a small amount or to warn them before they are speeding. A stronger warning should be given when a higher speed threshold has been exceeded (e.g., 10 mph over posted speed limit) to encourage teen drivers to slow down. Again, vehicle manufacturers should initially consider using the thresholds employed in the STC evaluation.

- To reduce annoyance the auditory alert should not occur more frequently than once every several minutes (e.g., 5 minutes was used in the STC evaluation). If a teen driver enters a new speed limit zone, such as a decrease in the speed limit, the amount of time between speed warnings provided to a driver should be reset (e.g., 5 minutes).
- The frequency of the speed warnings should be dependent on the speeds limit encountered while driving. Examples of adaptations for the mild and strong speed warnings are presented in Appendices A and B. While the specific values used in this research may serve as examples, the optimal warning algorithms and values are not known.
- It is recommended that mild and strong speed warnings be differentiated visually. A visual indication of a mild speed warning could consist of presenting the existing posted speed limit icon or presenting the existing posted speed limit icon with a yellow background to warn teen

drivers. The strong speed warning could consist of the speed limit icon with a red background (see Figure 20).

- All visual information provided by the Speed Monitoring and Feedback subsystem should be presented within 15 degrees field of view of a driver's central focal point on the roadway to reduce potentially negative effects of distraction. For example, speed information can be presented on the same display used for the presentation of all STC information. Where the speed limit is not recognized by the roadway database or if there is conflicting information regarding the speed zone the display should indicate that the speed is not known.
- The Speed Monitoring and Feedback subsystem feedback and vehicle adaptations should take precedence over feedback provided by other subsystems due to the high risk involved in speeding related incidents.
- The Speed Monitoring and Feedback subsystem should integrate information from allied subsystems (e.g., Passenger Presence Detection, Seat Belt Detection, Excessive Maneuver and Feedback, and Context) to adapt the feedback presented to teens. We support the inclusion of additional research that examines driver attitudes and potential behavioral changes in response to graded feedback (e.g., infotainment lockout at the strong warning).
- Discouraging unsafe high speeds should be a component of the Speed Monitoring and Feedback subsystem. This could include limiting the maximum speed of the vehicle (or at the very least by providing a warning to drivers who exceed an absolute maximum speed threshold). In light of the notion that most modern vehicles contain speed limiting mechanisms adding a speed limiting function based on STC-based information should be within the scope of most vehicle manufactures currently.

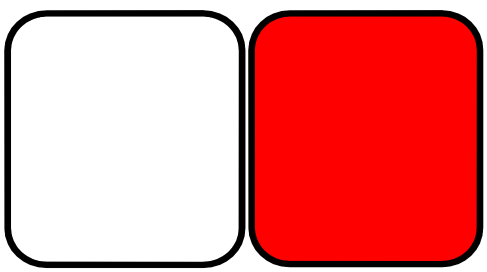

Figure 7. Visual display speed limit icons showing regulatory speed limit sign (left) and strong visual warning speed limit sign.

5. Excessive Maneuver and Feedback Subsystem

The Excessive Maneuver and Feedback subsystem monitors the motion of the vehicle with respect to lateral and longitudinal forces through the use of accelerometers. If a maneuver exceeds a predetermined threshold feedback to the teen driver is issued in the form of a visual icon and auditory alert. The extent of a maneuver was determined in the STC evaluation through the use of three axis accelerometers. Nearly identical technology is now being employed in modern vehicles and could easily provide maneuver information to a STC.

There is a need to provide excessive maneuver information to teen drivers and given the positive responses from the research effort we recommend implementing an Excessive Maneuver and Feedback subsystem identical or very similar to the one employed in the STC evaluation. The following section identifies the most relevant specifications for an Excessive Maneuver and Feedback subsystem.

5.1. Operational Specifications

- Inform the teen driver when an excessive maneuver has occurred (maneuver beyond a predetermined threshold). The STC evaluation employed thresholds identified in Appendix C and found some benefits. However, while these thresholds represent a promising starting point, it is recommended that vehicle manufacturers explore these thresholds further before implementation to determine which threshold levels might be most appropriate. For example, does the rate of feedback for both lateral and longitudinal maneuvers need to be similar (currently teens will likely receive more longitudinal feedback) or should only longitudinal feedback be provided since it is associated with a higher rate of negative events (e.g., rear end collisions) compared to lateral events?
- Feedback provided by the Excessive Maneuver and Feedback subsystem should be immediate and salient so that a teen driver can develop a clear association between the feedback and maneuver.
- Lateral excessive maneuver warnings suffered from poor comprehension in the STC evaluation. It is recommended that additional research be conducted to determine if comprehension can be improved through the use of directional warning (i.e., distinct warnings for the lateral and for the longitudinal excessive maneuver directions).
- Excessive maneuver feedback should incorporate an auditory component in addition to a visual component to reduce the potential for visual distraction.
- The excessive maneuver feedback should be sufficiently different from those used for vehicle-based warnings/feedback and allied subsystems. The STC evaluation employed the icon shown in Figure 21 because of high comprehension by drivers.
- Teens and their parents found the warning tone to be annoying. Vehicle manufacturers should consider reducing the auditory warning length to a maximum of five seconds and should consider modifying the tone type to reduce annoyance.
- The visual information should be displayed either in an instrument cluster or on a display within the field of view of the driver. Vehicle manufacturers should consider providing excessive maneuver and feedback information on a central display along with allied STC-based information.
- The Excessive Maneuver and Feedback subsystem should not be dependent on the operation of other STC subsystems.
- Excessive maneuver feedback (and speeding feedback) should take precedence over static warnings (e.g., seat belt).

Figure 8. Sample excessive maneuver icon displayed to STC drivers when an excessive maneuver is detected.

6. Driving Context Subsystem

The Driving Context subsystem employed in the STC evaluation compared current time of day information from a GPS time stamp against a table of known sunset and sunrise times as a surrogate index of whether a teen was driving during darkness. This information was then used by allied subsystems to reduce thresholds during nighttime driving. The GPS time stamp or similar time stamp already exists on most vehicles for the use of the CAN-bus system and could be employed by a STC. The Driving Context subsystem within the STC evaluation employed time of day information, however, additional contextual factors could be added. Specifications for the Driving Context Subsystem and additional contextual factors are presented in the following subsection.

6.1. Operational Specifications

- Warning and vehicle adaptation thresholds implemented by allied subsystems should be modified based on information gained from the Driving Context Subsystem.
- In light of the notion that nighttime driving increases risk for teen drivers it is recommended that the day/night contextual factor implemented in the STC evaluation be employed by vehicle manufacturers. This could be implemented by a comparison between time of day that is available on the existing CAN-bus and a database of sunrise/sunset times or through direct sensing of ambient conditions.
- Vehicle manufacturers could also include contextual information relative to specific weather conditions. This could include slippery conditions (e.g., rain, snow) as assessed through one or more existing vehicle-based systems (e.g., wiper activation, wheel spin, or anti-lock brake activation), gusty wind conditions as indicated by weather station information provided via standard radio signals, or icy road conditions inferred from a combination of temperature readings obtained from the vehicle and precipitation data obtained from weather station information.

7. Cell Phone Detection Subsystem

The goal of the Cell Phone Detection subsystem was to provide feedback to teen drivers and institute vehicle adaptations to allied subsystems (e.g., reducing feedback thresholds for speeding) if cell phone use was detected. This was intended to be a central feature of the STC to manage a known risk for teen drivers due to cell phone use, however, based on the results of preliminary pilot testing the available cell phone use detection technology proved to be unusable for the full STC evaluation due to poor reliability and accuracy. Furthermore, due to continued technological limitations for reliable and accurate cell phone use detection, adequate technology is still unavailable commercially. This is quite unfortunate as cell phone use (and texting) continues to be a significant risk factor for all drivers but especially teen drivers.

The significant risk associated with cell phone use would support the contention that the inclusion of *any* detection technology might be warranted and specified within a STC. However, based on teen and parent feedback within the pilot work conducted as part of this project, a poorly performing detection subsystem would be perceived as a significant annoyance and would negatively impact perceptions of the remaining subsystems. The result would be that teens and parents would view the entire STC negatively and would prefer not to use the system…an outcome that would deny teens the benefit of the other useful subsystems. In light of this we recommend that a Cell Phone Detection subsystem not be included in STC designs at this time. Instead, substantial effort should be dedicated to improving the accuracy and reliability this technology.

8. Adaptive Features

The adaptive features of the STC provided a novel way of influencing feedback for several subsystems based on the presence of specific risk factors. As an example, if a teen was driving at night the feedback thresholds for the Speeding Management and Excessive Maneuver subsystems were reduced. Similarly, if a teen was speeding the Excessive Maneuver subsystem feedback threshold was reduced. In this way there was an attempt to address/control at least one risk factor if another was detected. Based on the results and feedback from teens and their parents the following specifications are recommended.

- It is recommended that the adaptive capability of STC subsystems through the use of threshold modification be implemented in future systems developed by vehicle manufacturers. The ability to address/control at least one risk factor (e.g., speeding) when another risk factor is present (e.g., presence of multiple teens) represents a significant advancement over existing teen driver support systems. Implementation of this feature by vehicle manufacturers can be achieved by through the use of existing vehicle-based STC subsystem sensor equipment (e.g., seat belt sensor, passenger presence sensor), small databases like those that appear in Appendices A, B, and C, and computer programs that consider the necessary interrelationship between sensor-based information and the databases.
- Modifications to subsystem thresholds represent one form of STC adaptation. A second form of adaptation relates to hardware. In particular, if specific risk factors are present vehicle-based hardware can be controlled to promote less teen driver risk taking. As an example, within the demonstration activity of the current project the vehicle's radio was muted when a speed or excessive maneuver warning was presented. We recommend that the

scope and nature of the potential interlocks or other aspects of vehicle response be examined relative to teen driving behaviors and perceptions. Potential hardware adaptations could include speed limiters due to the presence of high-risk factors such as passenger presence or speeding, or radio muting due to cell phone use.

9. Other Functions

The present study focused on speeding, seat belt use, cell phone use, and excessive maneuvers as prominent factors in teen driving performance and crash risk. This should not imply that these are the only relevant candidate behaviors for monitoring. Emerging technologies that may be present in many future vehicles could be incorporated into a STC. Examples include the sensing of visual distraction, fatigue, alcohol impairment, excessive sound levels, inappropriate vehicle following distances, and lane drifts.

References

Lerner, N., Jenness, J., Singer, J., Klauer, S., Lee, S., Donath, M., Manser, M., & Ward, N. (2010). *An Exploration of Vehicle-Based Monitoring of Novice Teenage Drivers.* (Report No. DOT HS 811 333). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Human%20Factors/ Reducing%20Unsafe%20Behaviors/%EF%BB%BFDOT%20HS%20811%20333.pdf

This report also included information and data from unpublished reports delivered to NHTSA as interim Task Orders, as follows:

Graving, J., Edwards, C., Manser, M., Easterlund, P., Lerner, N., Jenness, J., and Huey, R. (2011). *An Evaluation of a Prototype Safer Teen Car: Conduct Evaluation of Subsystems.* Interim project report under Contract DTNH22-08-D-00115 TO 2.

Gorjestani, A., Menon, A., Arpin, A., Cheng, P., Huey, R., Lerner, N., & Jenness, J. (2010). *An Evaluation of a Prototype Safer Teen Car: Determine Enabling Technologies that meet the Functional and Interface Specifications.* Interim project report under Contract DTNH22-08-D-00115 TO 2.

Manser, M., Edwards, C., Lerner, N., Jenness, J., & Huey, R. (2012). *An Evaluation of a Prototype Safer Teen Car: Final Report* Interim project report under Contract DTNH22-08-D-00115 TO 2.

Manser, M., Graving, J., Rakauskas, M., Creaser, J., Lerner, N., Jenness, J., & Huey, R. (2010a). *An Evaluation of a Prototype Safer Teen Car: Specify Subsystem Functions and their Performance Requirements.* Interim project report under Contract DTNH22-08-D-00115 TO 2.

Manser, M., Graving, J., Rakauskas, M., Lerner, N., Jenness, J., and Huey, R. (2010b). *An Evaluation of a Prototype Safer Teen Car: Develop and Review Data Collection and Analysis Plan.* Interim project report under Contract DTNH22-08-D-00115 TO 2.

Appendix J-1

Speed warning thresholds corresponding to various posted speed limits.

Posted Speed Limit	Mild Warning Threshold	Maximum Contextual Speed Increment*	Strong Warning Threshold Range	Maximum Speed Threshold
Less than 25 mph	posted speed limit (+2 mph)	0 mph	posted speed limit (+2 mph)	80 mph
25 mph	27 mph	+5 mph	27 to 30 mph	80 mph
30 mph	32 mph	+10 mph	32 to 40 mph	80 mph
35 mph	37 mph	+10 mph	37 to 45 mph	80 mph
40 mph	42 mph	+10 mph	42 to 50 mph	80 mph
45 mph	47 mph	+10 mph	47 to 55 mph	80 mph
50 mph	52 mph	+15 mph	52 to 65 mph	80 mph
55 mph	57 mph	+15 mph	57 to 70 mph	80 mph
60 mph	62 mph	+15 mph	62 to 75 mph	80 mph
65 mph	67 mph	+15 mph	67 to 80 mph	80 mph
70 mph	72 mph	+10 mph	72 to 80 mph	80 mph
75 mph	77 mph	+5 mph	77 to 80 mph	80 mph
80 mph	80 mph	0 mph	80 mph	80 mph
Unknown	none	none	none	80 mph

Note, “ * ” indicates variable representing miles per hour over the posted speed limit.

Appendix J-2

Strong auditory speed warning thresholds with cautionary inputs from other subsystems.

Posted Speed Limit	Auditory Speed Warning Threshold				
	No Cautionary Inputs	Seat Belt Violation	One Cautionary Input	Two Cautionary Inputs	Three or More Cautionary Inputs
Less than 25 mph	posted speed limit +2 mph	posted speed limit +2 mph	posted speed limit +2 mph	posted speed limit +2 mph	posted speed limit +2 mph
25 mph	+5 mph	posted speed limit +2 mph	+ 3 mph	posted speed limit +2 mph	posted speed limit +2 mph
30 to 45 mph	+10 mph	posted speed limit +2 mph	+6 mph	+3 mph	posted speed limit +2 mph
50 to 65 mph	+15 mph	posted speed limit +2 mph	+10 mph	+5 mph	posted speed limit +2 mph
70 mph	+10 mph	posted speed limit +2 mph	+6 mph	+3 mph	posted speed limit +2 mph
75 mph	+5 mph	posted speed limit +2 mph	+ 3 mph	posted speed limit +2 mph	posted speed limit +2 mph
80 mph	posted speed limit	posted speed limit	posted speed limit	posted speed limit	posted speed limit

Appendix J-3

Auditory excessive maneuver warning thresholds with cautionary Inputs from other subsystems.

Posted Speed Limit	Auditory Excessive Maneuver Warning Threshold				
	No Cautionary Inputs	Seat Belt Violation	One Cautionary Input	Two Cautionary Inputs	Three or More Cautionary Inputs
Less than 25 mph	.50 g	.45 g	.45 g	.40 g	.35 g
25 mph	.50 g	.45 g	.45 g	.40 g	.35 g
30 to 45 mph	.50 g	.40 g	.40 g	.35 g	.30 g
50 to 65 mph	.50 g	.35 g	.35 g	.30 g	.30 g
70 mph	.50 g	.30 g	.30 g	.30 g	.30 g
75 mph	.50 g	.30 g	.30 g	.30 g	.30 g
80 mph	.50 g	.30 g	.30 g	.30 g	.30 g

Note, darker shading indicates stringent criterion thresholds.

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